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The SPAR-H Human Reliability Analysis Method

Idaho National Laboratory

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ABSTRACT

In support of the Accident Sequence Precursor Program (ASP), the U.S. Nuclear Regulatory Commission (NRC), in conjunction with the Idaho National Laboratory (INL), in 1994 developed the Accident Sequence Precursor Standardized Plant Analysis Risk Model (ASP/SPAR) human reliability analysis (HRA) method, which was used in the development of nuclear power plant (NPP) models. Based on experience gained in field-testing, this method was updated in 1999 and renamed SPAR-H, for Standardized Plant Analysis Risk-Human Reliability Analysis method. Since that time, NRC staff analysts have been using this method to perform their risk-informed regulatory activities, such as determining the risk significance of inspection findings in Phase 3 of the Significance Determination Process, developing an integrated risk-informed performance measure in support of the reactor oversight process, and systematically screening and analyzing operating experience data in order to identify events/conditions that are precursors to severe accident sequences. As a result of implementation by staff analysts, and from other experience gained at the INL in applying the method in human reliability analysis (HRA), a number of needed improvements to definitions, terms, and concepts were identified. In 2003, to enhance the general utility of the SPAR-H method and to make it more widely available, the method was updated and reviewed for its applicability to low-power and shutdown applications. During this review, an approach to uncertainty representation was outlined, based on the beta distribution. Additional detail regarding human error probability (HEP) dependency assignment was also made available.

This document presents the current version of the SPAR-H method, along with guidance, definitions, improvements in representing uncertainty, and increased detail regarding dependency assignment for HEP calculations. This report also contains comparisons between this and other contemporary HRA approaches and findings specific to application of the method to low power and shutdown events.

FOREWORD

In the early 1990s, the U.S. Nuclear Regulatory Commission (NRC) identified the need for an improved, traceable, easy-to-use human reliability analysis (HRA) method for use with the analytical models associated with the agency's Accident Sequence Precursor (ASP) Program. This report documents the most recent update of the Standardized Plant Analysis Risk (SPAR) HRA (SPAR-H) Method, which evolved in response to this need.

Initially, the NRC contracted with Idaho National Laboratory (INL)[1] to develop the "ASP SPAR HRA Method," which consisted of a two-step process to identify nominal human error probabilities (HEPs), and then modify those HEPs on the basis of summary-level performance-shaping factors (PSFs) and dependence. Significantly, this method required analysts to complete a relatively straightforward worksheet, which was then used to estimate the PSFs and the HEP of interest. Then, in 1999, the NRC directed INL to update the ASP SPAR HRA Method by modifying the PSFs, dependencies, and base HEPs using a benchmarking process, and the modified method was renamed as the "SPAR-H Method." Most recently, in 2002–2003, the NRC asked INL to update the model to (1) improve definitions, terms, and concepts; (2) produce a reference document; (3) review the applicability of the SPAR-H Method to low-power and shutdown applications; (4) develop a treatment approach for uncertainties associated with human performance parameters; and (5) present additional detail regarding assignment of HEP dependencies. This report presents the results of this work, which have undergone peer review by internal and external stakeholders.

Over time, NRC analysts have come to use the SPAR models and SPAR-H Method extensively in performing their risk-informed regulatory activities in a variety of agency programs. The SPAR-H Method is an adequate HRA tool for use with the SPAR models in performing risk analyses of operational events/conditions. In particular, the affected programs include the ASP Program, the Significance Determination Process (SDP), generic issue resolution, and license amendment reviews. Nonetheless, as a simplified method, SPAR-H has inherent modeling and analysis limitations that should be clearly understood. The SPAR-H Method should not necessarily be preferred over more sophisticated and detailed approaches, such as A Technique for Human Event Analysis (ATHEANA), in situations that require detailed analysis of the human performance aspects of an event.

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[1] Idaho National Laboratory was formerly known as Idaho National Engineering and Environmental Laboratory (INEEL). The name change occurred in February 2005, when the U.S. Department of Energy entered into an agreement with a new contractor to manage the laboratory.

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EXECUTIVE SUMMARY

Human performance has been a key component of incidents and accidents in many industries. Recently, the role of human error was documented in a number of well studied, high-profile events in the nuclear power industry (Gertman et al. 2002). Studies of these events included human reliability analysis (HRA). Human reliability analysis is an evolving field that addresses the need to account for human errors when: (a) performing safety studies such as probabilistic risk analysis (PRA); (b) helping to risk-inform the inspection process; (c) reviewing special issues; and (d) helping to risk-inform regulation. HRA has also been used to support the development of plant-specific PRA models.

This report presents a simple HRA method for estimating the human error probabilities associated with operator and crew actions and decisions in response to initiating events at commercial U.S. nuclear power plants (NPPs). The Standardized Plant Analysis Risk Human Reliability Analysis (SPAR-H) method was developed to support development of plant-specific PRA models for the U.S. Nuclear Regulatory Commission (NRC), Office of Regulatory Research (RES), and recently has been used to help support the Office of Reactor Regulation (NRR) Reactor Oversight Process (ROP). The SPAR-H method is also applicable to preinitiator events.

The basic SPAR-H framework:

- Decomposes probability into contributions from diagnosis failures and action failures
- Accounts for the context associated with human failure events (HFEs) by using performance-shaping factors (PSFs), and dependency assignment to adjust a base-case HEP
- Uses pre-defined base-case HEPs and PSFs, together with guidance on how to assign the appropriate value of the PSF
- Employs a beta distribution for uncertainty analysis
- Uses designated worksheets to ensure analyst consistency.

Based on review of first- and second-generation HRA methods, the SPAR-H method assigns human activity to one of two general task categories: action or diagnosis. Examples of action tasks include operating equipment, performing line-ups, starting pumps, conducting calibration or testing, and other activities performed during the course of following plant procedures or work orders. Diagnosis tasks consist of reliance on knowledge and experience to understand existing conditions, planning and prioritizing activities, and determining appropriate courses of action. Base error rates for the two task types associated with the SPAR-H method were calibrated against other HRA methods. The calibration revealed that the SPAR-H human error rates fall within the range of rates predicted by other HRA methods.

A number of HRA methods do not have an explicit human performance model. The SPAR-H method is built on an explicit information-processing model of human performance derived from the behavioral sciences literature that was then interpreted in light of activities at NPPs (Blackman and Byers 1994). In 1999, further research identified eight PSFs capable of influencing human performance. These PSFs are accounted for in the SPAR-H quantification process. These factors include:

- Available time
- Stress and stressors
- Experience and training
- Complexity
- Ergonomics (including the human-machine interface)
- Procedures
- Fitness for duty
- Work processes.

While many contemporary methods address PSFs in some form, the SPAR-H method is one of the few that addresses the potential beneficial influence of these factors. That is, positive influences of PSFs can operate in some instances to *reduce* nominal failure rates. For example, superior experience and training can serve to enhance the operator's understanding of system status beyond the average or nominal case. This does not mean that the operator or crew's knowledge is necessarily complete, merely that it is better by some objective measure, which can enhance performance. Figure ES-1 shows this relationship and the influence of the PSF (*x*-axis) on mean human error probability (HEP) values (*y*-axis).

The SPAR-H method addresses dependency. *Dependency*, in this case, means that the *negative* influence of a human error on subsequent errors is accounted for by the model and is reflected in calculating the HEP. The model does not explicitly address the influence of positive dependency on subsequent failures; in these situations, analysts are expected to use nominal rates when determining the HEP for subsequent failures.

Although the literature on dependency among human errors is limited, the INL review determined that the presence of the following combinations of factors contributes to error dependency:

- Same crew (relates to similar mindset, use of similar heuristics, tendencies to tunnel vision, recency effects, etc.)
- Same location (the control, display, or equipment must be the same or located within the same relatively restricted area, such as the same panel)

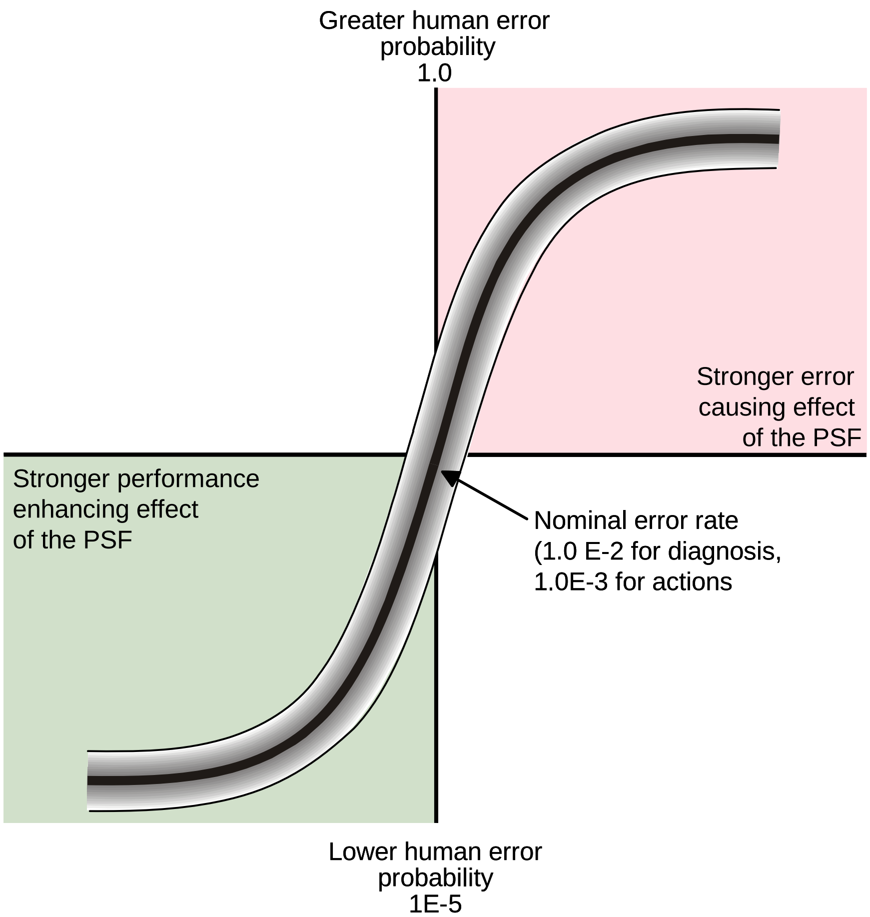

Figure ES-1. Ideal mean HEP as a function of the influence of performance shaping factors.

- Lack of additional cues [additional cues exist if there is a specific procedural callout or a different procedure is used, or additional alarm(s) or display(s) are present]
- Close succession of the next HEP (from within seconds to a few minutes).

Various combinations of these contributory factors were examined and given a rating based on their combined effect on dependency among tasks. The ratings of the various combinations correspond to zero, low, moderate, high, or complete dependency among tasks. In integrating this dependency information, the SPAR-H method uses the underlying THERP quantification provided in NUREG/CR-1278 (1983), but offers an improved basis for dependency assignment.

Once dependency has been determined to be present, moderate-to-high dependency will dominate the failure rate obtained when applying the SPAR-H method; however, satisfying the requirements for this level of dependency is not often met. This restriction occurs because many actions involve different steps in procedures and provide for relatively long periods of time between actions. In addition, the location of the equipment acted upon is not similar. Conversely, dependency assignment is almost always applicable in situations where an HRA analyst is attempting to model the influence of a second or third checker in a recovery sequence.

The SPAR-H method may be applied on a task level [as is often the case when developing SPAR models for low power/shutdown (LP/SD) or at-power], or on a subtask level when building HRA event trees or fault trees (i.e., performing more detailed analysis). Once a decision regarding the level of decomposition has been determined, the application of SPAR-H on either the task or subtask level should be consistent within the PRA. While minor differences in HEP estimates for failure events may be exhibited on the basis of the level of decomposition selected, this problem should not dominate findings of the risk analysis and is not unique to SPAR-H. In the event that there are applications where the level of event decomposition is thought to lead to different results, we suggest that the analyst perform the analysis at both levels of decomposition, review the results of each, and then select the most appropriate decomposition level.

SPAR-H has been used in the development of plant models and in event analysis, and it is possible to apply the method to retrospective as well as prospective scenarios. The criterion for applying the SPAR-H method dependency assignment is the same for either case.

The application of the SPAR-H method is relatively straightforward and follows the guidance for conducting HRA, which is available in a number of publicly available sources. Such sources include IEEE Standard 1082 for HRA (1997), ASME Standard for Probabilistic Risk Assessment (ASME STD-RA-S-2002), and EPRI's 1984 Systematic Human Action Reliability Procedure (SHARP; Hannaman and Spurgin 1984). A number of analysts within the industry may also have access to SHARP1 (Wakefield, Parry, and Spurgin 1990), but distribution is limited. When applied to situations other than SPAR model building or screening situations, the comprehensive HRA search strategies found in NUREG-1624 (2000) can be used to aid in identifying and modeling errors leading to unsafe acts and human failure events.

The SPAR-H method produces a simple best estimate for use in plant risk models. The mean is assumed to be the best (i.e., most informative) piece of information available regarding the human error probability. In addressing uncertainty, error factors were not used, and the use of a lognormal probability distribution was not assumed. The SPAR-H method employs a beta distribution, which can mimic normal and lognormal distributions, but it has the advantage that probabilities calculated with this approach range from 0 to 1. A constrained noninformative prior, based on Atwood (1996), was selected for its ability to preserve the overall mean value while producing values at the upper end of the distribution that more accurately represent the expected error probability. Analyses contained in this report also review human performance distributions, relate them to performance shaping factors, and discuss issues regarding the relative orthogonality of performance shaping factors' influence on human performance.

A major component of the SPAR-H method is the SPAR-H Worksheet, presented in Appendices A and B. The method for filling out these worksheets is described in this report. Note that the process differs slightly, depending on whether the analyst is using the method to build SPAR models, perform event analysis, or perform a more detailed HRA analysis. The analysis presented below refers to the use of the SPAR-H method to support SPAR PRA model development, the major focus for the HRA method development process.

SPAR-H WORKSHEET PROCESS OVERVIEW

In most instances, the HRA analyst will review SPAR model event trees containing action or diagnosis tasks and accompanying contextual information for consideration and evaluation. In the majority of instances, the event will require analysis on a task level, that is, multiple subtasks are considered. Event trees and a limited number of fault trees will be available from the PRA analyst. The HRA analyst will determine whether actions specified involve diagnosis or are purely action-based. In some instances, action and diagnosis are intertwined and indiscernible. In others, a step in SPAR events may represent a task with many underlying subtasks, including planning or diagnosis. In such instances, the basic event in the PRA model represents both diagnosis and action. If a task involves both action and diagnosis, two worksheets corresponding to action and diagnosis are filled out, and a joint HEP is calculated. This event is later reviewed for dependency (see below).

When developing the basic SPAR-H model, three of the eight PSFs are evaluated: time available, stress and stressors, and complexity. The remaining five PSFs (experience, procedures, ergonomics and human-machine interface, fitness for duty, and work processes) are generally rated nominal, because they are usually event-, plant-, or personnel-specific. These five PSFs are evaluated when a plant-specific model is being developed.

Following determination of task category, the relationship of a failed task to a preceding failed task (i.e., the task dependency) is assessed according to SPAR-H definitions. This dependency is then used to support quantification of the final HEP.

Since there is some overlap among PSFs, there is a possibility that an influence might be double counted, and analysts should be cautious in this regard. In addition, in highly negative situations, i.e., strong negative contexts, where the propensity for error is high, it is possible that analysts' assignment of PSF levels can result in the calculation of a mean that would be numerically larger than 1. In previous versions of the SPAR-H method, the general guidance was to round the HEP estimate to 1. A mathematical solution for this problem was sought, and a corresponding adjustment factor was developed to avoid probability estimates greater than 1. This adjustment factor for use of multiple negative PSFs is presented on the worksheets. We suggest that the adjustment factor be used in situations where at least three nonnominal (negative) PSFs have been identified. (For a more detailed review see Section 2.5.) No adjustment factor for positive PSFs was developed. The positive influence of dependency has not been investigated and therefore is not part of the SPAR-H method. A lower bound cut-off of 1.0E-5 for HEPs is suggested.

SPAR-H WORKSHEET PROCESS

The mechanics of completing the SPAR-H human error worksheets are as follows.

Step 1. Enter header information. This information refers to the:

- Plant being rated
- Name of the initiating event [e.g., partial loss of offsite power (LOSP)]
- Basic event code [e.g., failure to restore one of the emergency diesel generators (EDG), XHE – LOSP – EDG]
- Coder ID [i.e., name of the analyst filling out the worksheet(s)]
- Context of the basic event being rated (e.g., previous events in this particular sequence)
- General description of the event being rated (e.g., operator fails to perform correct action).

Step 2. Decide whether the basic event involves diagnosis, action, or both diagnosis and action.

Step 3. If diagnosis is involved, then rate the eight PSFs according to the guidance provided. Use one check mark for each PSF. Note any time a nonnominal PSF value is selected; document the reason for both nominal and nonnominal PSFs.

Step 4. Transfer the multipliers to the calculation portion of the worksheet.

Step 5. Determine the HEP without dependency ($P_{\text{w/od}}$). If there are 3 or more negative PSFs, then apply the adjustment factor provided on the worksheets (Section 2.5).

Step 6. If action is involved, repeat Steps 3–5 for the action portion.

Step 7. Calculate the overall HEP total, using the diagnosis HEP, the action HEP, or the joint HEP.

Step 8. Determine the appropriate level of dependency from the table. If there is no dependency, document why there is none in the space provided. If there is no dependency, then the total HEP is that produced in Step 7.

Step 9. If dependency criteria are met and a level of dependency has been assigned, then calculate the task failure probability with formal dependence, by using the worksheet.

Appendices C, D, and E present examples of the worksheet.

COMPARISON OF LP/SD AND AT-POWER CONDITIONS

As a result of a qualitative comparison of LP/SD and at-power condition, we determined that a separate worksheet for LP/SD and at power conditions should be developed. The worksheet for at power is presented in Appendix A, while the worksheet for LP/SD is presented in Appendix B. Findings from field test results of the SPAR-H method led to improvements in the LP/SD and at-power worksheets. The following enhancements to earlier versions of the worksheet were implemented:

LP/SD Worksheet Enhancements

PSF Time Available for Actions. The dynamic range of influence for expansive time available defined as 50x nominal, was changed. The range of effect for expansive time now reduces the nominal rate by a multiplier of 0.01. When time available is determined to be 5x nominal, then a multiplier of 0.1 is used.

PSF Procedures. An additional level of influence was incorporated for LP/SD. Incomplete or partial procedures influence the base HEP by a factor of 20. This influence is present for action and diagnosis tasks. Analysts commented that this assignment would potentially be valuable for at-power conditions as well, and this level has also been applied to the at-power worksheets.

PSF Time Available for Diagnosis. Time available multipliers were developed. Diagnoses with extra available time available ranging from between 1 to 2x nominal are assigned a multiplier of 0.1; expansive time (defined as >2x nominal) is assigned a range of effect from 0.1 to 0.01, which may be assigned by the analyst. This better reflects the increased uncertainty and longer time horizons associated with a number of LP/SD tasks.

PSF Complexity. An additional level of influence for favorable complexity (i.e., obvious diagnosis) was developed. The multiplier associated for this category is 0.1.

At-power Worksheet Enhancements

PSF Time Available for Actions. The dynamic range of influence for expansive time available was changed. The range of effect for expansive time now uses a multiplier of 0.01. In addition to the use of absolute minutes in earlier versions of SPAR-H, the relative time available in conjunction with the time required for task performance has been taken into account.

PSF Procedures. An additional level of influence was incorporated. Incomplete or partial procedures influence the base HEP by a factor of 20. This influence is present for action and diagnosis tasks.

PSF Time Available for Diagnosis. The influence of expansive time (≥24 hours for diagnosis for at-power conditions) was changed from a multiplier of 0.001 to 0.01.

An additional PSF category, "Insufficient Information Available," was added to both worksheets for each individual PSF.

DISCUSSION

The SPAR-H method is straightforward, easy to apply, and is based on a human information-processing model of human performance and results from human performance studies available in the behavioral sciences literature (Newell and Simon 1972). This simplified HRA approach contains a number of significant features, including calibration of its base failure rates and range of PSFs' influence with other HRA methods. This version of the SPAR-H method also contains a revised approach to uncertainty analysis, employing a beta distribution that obviates problems experienced in earlier versions when applying error factor approaches, and an adjustment factor for situations where the estimate of the mean HEP is greater than 1.

SPAR-H has been refined as a result of experience gained during its use in the development of over 70 SPAR PRA plant models for the NRC, in limited HRA applications for dry cask spent-fuel storage, in implementation of risk-informed plant inspection notebooks, and through third party application to other domains such as aerospace. The method does not differentiate between active and latent failures. Identification and modeling of human failure as either active or latent is the decision of the analyst. It is thought that the same PSFs and base failure rates are applicable to either type of error. The base error rates contained in the worksheets for actions and diagnosis include omission and commission types of errors; the explicit representation of omission versus commission is an issue left to the analyst and is part of the error identification and modeling process constituting HRA. This is in contrast to other, more in-depth methods such as ATHEANA, which focuses on the identification and quantification of errors of commission.

If, in the judgment of the PRA and HRA analyst, additional detailed analyses are called for, the tendency for either omissions or commissions to be more important in contributing to an individual human failure event can be explicitly modeled by the analyst. For example, the subtask level of decomposition can be used when building supporting fault trees.

The explicit incorporation of work processes in PRA/HRA is relatively new. First generation methods acknowledged work practices when taking into account the use of a second checker or procedure quality. In instances where the work process PSF is thought to influence performance, it is often difficult to determine its effects. This is, in part, because the effects of work processes and organizational factors are often diffuse. For example, the amount of workarounds, failure to trend problems, and failure to respond to industry notices may increase the likelihood of equipment unavailability, increase the likelihood of errors, and/or reduce the likelihood of error recovery.

The range of effect used in SPAR-H reflects the treatment of the work process PSF in other HRA methods. For example, work processes range of effect in SPAR-H is enveloped by identification of a range of effect for work process PSF in two methods, CREAM (Hollnagel 1998) and HEART (Williams 1992). The work process PSF definition owes some debt to the work process analysis method (WPAM) found in Weil and Apostolakis (2002). Obviously, other HRA methods, including those making use of simulator trials such as MERMOS (Bieder et al. 1999), do not have a direct work process parameter from which a range of effects could be used to inform SPAR-H. The same is true for the ORE/CBDT (EPRI TR-100259 1992) approach. The ORE/CBDT provides normalized time reliability curves, a cue response model, and yes/no decision trees for different failure modes. Formal communication and compliance failures are represented in a subset of the trees. Other aspects of work practices may be implicitly present in the time reliability curves. However, extracting the relative range of effect is somewhat difficult and the ORE/CBDT model was not designed with balance of plant operations or preinitiator failures in mind. Thus, the range in

SPAR-H is within the bounds suggested by the other HRA methods above.

Traditionally, accounting for the influence of multiple shaping factors with multiple levels of influence without imposing a high degree of expert consensus judgment on the HRA process has proven difficult for HRA. SPAR-H attempts to help make the assignment of human error probability a more repeatable function and less a function of the analyst performing the HRA. We believe that the analyst's expertise comes into play in discovery of the appropriate error and in assigning the correct level of influence (i.e., multiplier for the HEP). The HRA search process for determining unsafe acts given a particular context still remains a challenging task for the PRA/HRA analyst, but this is the information that is brought to SPAR-H for quantification. The need to provide sound qualitative assessments of factors is amplified as SPAR-H applications expand beyond basic plant PRA model development to include HRA for event analysis and the evaluation of specific plant performance issues.

CAVEATS

As does any simplified method, SPAR-H has modeling and analysis limitations that should be clear. We list several of these limitations here. SPAR-H does not address in detailed fashion how to incorporate SPAR basic events into system event trees. It does provide guidance, however, to calculate or estimate the probabilities associated and the dependencies between those events once the analyst has determined the appropriate system model structure. SPAR-H offers a means for estimating the probability associated with recovery attempts; the analysts can use the worksheet to explicitly model and quantify recovery attempts. A person's recovery from his or her individual error is often the product of interface quality and systems feedback, procedures quality, training and experience, and supporting work processes. These factors are reflected in the PSF assignment that modifies the nominal rate. *Functional systems recovery* as used in PRA is not recovery from an individual error per se but the restoration of function, and can involve many tasks.

An example of the type of information not covered in great detail in this report is a tutorial on how to construct fault trees that represent subsequent actions, such as crew recovery. Other sources of information, such as the ASME Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications (2002), the PRA Procedures Guide (NUREG/CR-1278 1983), or the NRC Fault Tree Handbook (Veseley et al. 1981), do address these modeling issues in depth, including different search strategies that can be used to identify human failure events.

We believe that the PSFs used in SPAR-H account for most of the performance influences that will be observed in events and are the PSFs most applicable to support SPAR models. Potentially, there may be difficulty when reviewing an event in deciding the assignment of a particular influence to one of the PSF categories. For example, in the case of a preinitiator, poor work package development coupled with evidence of poor communications during pre-evolution briefing can potentially increase the likelihood of error during maintenance activities. In this instance the work package development influence needs to be mapped to the work practices PSF in SPAR-H. In almost all cases, different types of PSFs that appear in other HRA methods or that are developed through the analyst's understanding of an operating event can be assigned to one of the eight PSFs appearing in SPAR-H.

There may be rare cases in which it is difficult to map the analyst assignments to the specific PSFs in SPAR-H. These cases are not a major concern, because SPAR-H encourages documentation of the assumptions underlying PSF assignments. Three considerations apply when mapping an analyst assignment to a PSF. First, the most important aspect of flagging a particular PSF is that the analyst makes appropriate adjustments to the HEP, that is, calls attention to the fact that a non-nominal condition exists. If a specific PSF does not fully apply, the analyst should indicate this in the HRA analysis but nonetheless make adjustments to the HEP. Second, assignment of extreme PSF values requires that the analyst have strong justification for the assignment, and that he or she indicate the reasons for said assignment within the body of the HRA analysis. Third, the effect of an individual PSF assignment may be diminished, depending where the HEP appears in the fault tree or event tree structure and PRA model. In general, the HRA practitioner needs to collect details on the scenario, including what information the crew needs, how they obtain this information, and any factors that could interfere with them reaching a proper diagnosis.

Although it would be preferable to have empirically derived PSF distributions, the probability density functions (PDFs) employed in SPAR-H make use of the same theoretical distributions that have been used in other HRA methods. At the time that the SPAR-H work was performed, we were not able to benchmark against experimental or experiential data from the nuclear industry. We conducted a review process, and the PSFs used in SPAR-H are supported by findings contained in the behavioral sciences literature. The PSFs are present in most other HRA methods, and can be mapped to findings regarding the characterization of errors present in operating events (see Gertman et al. 2002). The NRC is in the process of examining human performance data on PSFs systematically collected by the Halden Reactor Project and reviewing similar information taken from LERs under the NRC HERA HRA database project under Job Code Number Y6123.

Last, SPAR-H allows for flexibility. Analysts can decompose to different levels, as well as make their own determinations regarding whether important transitions such as those between procedures need to be individually identified in PRA system models. In the case of SPAR model development; these transitions in procedure usage are not modeled as diagnostic basic events. Typically, transitions are captured within a system-level basic event. For example, the operation of safety systems such as injection or heat removal is represented as a single HEP for the operation of that system, even though multiple transitions may be required. If the transition process is problematic and thought to influence performance, the analyst employing SPAR-H has the flexibility to increase the nominal rate by assigning an appropriate non-nominal PSF level to either complexity or to the procedures PSF.

The current version of SPAR-H does not differentiate in terms of PSF levels between pre- versus postinitiator actions. The reason for this is that a general model of human performance is assumed, and any differences noted in performance can be accounted for through the proper application of PSFs. A priori, in his or her analysis, the HRA practitioner has indicated whether the HEP under evaluation is more suitably addressed as a pre- versus postinitiator. People are not different before and after an event except to the extent that the event and its context provide feedback, raise or lower stress, call on operator training and knowledge, interfere with information processing, reduce the availability of job performance aids, influence complexity, or otherwise affect PSFs that are defined in the method.

Although it would be advantageous to be able to address uncertainty in more detail, at present it is difficult to determine the contribution of aleatory versus epistemic sources of uncertainty on the HEP as a function of PSF influences and interactions. This is beyond the scope of a simplified HRA method. However, we note numerous potential research avenues that could further our understanding in this area.

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ACRONYMS

AFWD	auxiliary feedwater
AIT	Augmented Inspection Team
ASEP	Accident Sequence Evaluation Program
ASME	American Society of Mechanical Engineers
ASP	accident sequence precursor
ATHEANA	A Technique for Human Event Analysis
BWR	boiling water reactor
CAHR	Connectionism Approach to Human Reliability
CAP	corrective action plan
CCDP	conditional core damage probability
CCP	centrifugal charging pump
CN	constrained non-informative
CNI	constrained non-informative prior
CREAM	Cognitive Reliability Evaluation and Analysis Method
CRO	control room operator
CRS	control room supervisor
CS	containment sump
CS	core spray
DG	diesel generator
EF	error factor
EFC	error forcing context
EOC	Emergency Operations Center
EOC	error of commission
EOP	emergency operating procedure
EPRI	Electric Power Research Institute
ESF	engineered safety features
FLIM	Failure Likelihood Index Method
FMEA	failure mode and effects analysis
FSAR	Final Safety Analysis Report
HEART	Human Error Analysis and Reduction Technique
HEP	human error probability
HF	human factors
HF PFMEA	human factors process failure modes and effects analysis
HFE	human failure events
HLR-HE-E	High Level Requirements for Human Error (ASME def.)
HMI	human machine interface
HPI	high-pressure injection
HRA	Human Reliability Analysis
INL	Idaho National Laboratory
IPE	individual plant examination
LB	lower bound
LCO	limiting condition of operation
LDST	let-down storage tank
LER	licensee event report
LOI	loss of inventory
LP/SD	low power and shut down
LTM	long-term memory
MERMOS	Methode d' Evaluation de' la Reaslisation des Missions Operateur pour la Surete'
MMPI	Minnesota Multiphasic Personality Inventory
MOV	motor-operated valve
MSIV	main steam isolation valve
NASA	National Aeronautics and Space Administration
NASA JSC	National Aeronautics and Space Administration Johnson Space Center
NPP	nuclear power plant
NRC	Nuclear Regulatory Commission
NSO	nuclear service operator
PM	plant management
PRA	probabilistic risk assessment
PSF	performance shaping factors
P_{wd}	probability (human error) with dependency
$P_{w/od}$	probability (human error) without dependency
PWR	pressurized water reactor
RCP	reactor coolant pump
RCS	reactor coolant system
RHR (S)	residual heat removal system
RI	resident inspector
ROP	reactor oversight process
RPV	reactor pressure vessel
RX	reactor
SAPHIRE	Systems Analysis Program for Hands-On Integrated Reliability Evaluation
SAR	Safety Analysis Report
SBCV	Safety block control valve
SCUBA	self-contained breathing apparatus
SD	shutdown
SG	steam generator
SGTR	steam generator tube rupture
SHARP	Systematic Human Action Reliability Procedure
SLIM	Success Likelihood Index Method

SPAR	standardized plant analysis risk
SRV	safety relief valve
SS	shift supervisor
STD	Standard
SM	secondary memory
STM	short-term memory
TH	thermal hydraulics
THERP	Technique for Human Error Rate Prediction
TLX	Task Load Index
TOC	Technical Operations Center
TRC	time-reliability curve
TS	Technical Specifications
TSC	Technical Support Center
UA	unsafe acts
UB	upper bound

GLOSSARY

Adjustment factor—The product of the performance shaping factor (PSF) multipliers. The adjustment factor is only calculated when three or more negative PSFs are present. The product is then used in the adjustment formula in conjunction with the nominal human error potential (HEP) to produce the overall HEP. This helps to reduce double counting of effects and restricts the calculated mean value from being greater than 1. In situations where there are 2 or fewer negative PSFs, the PSF values are directly multiplied with the nominal human error probability, and the adjustment factor is not used.

ASP SPAR (1994)—Accident Sequence Precursor Standardized Plant Analysis Risk; includes original iteration of SPAR-H, with following characteristics: Process and diagnostic task distinction, no uncertainty information beyond adoption of error factors typically used in other methods, Swain quantification approach to dependency.

Basic event—The term used in this report to describe a component failure, loss of function, unavailability, or failed human action in a SPAR model event tree. An example of a basic event might be "Operator fails to throttle high-pressure injection (HPI) to reduce pressure."

Error mode—*Error type* is also referred to as *error mode*. Major categorization schemes associated with first-generation methods include omission or commission that can occur within the skill-, rule-, and knowledge-based domains. Second-generation methods use terminology such as *slips*, *lapses*, and *mistakes*, where the latter have a large cognitive component that is accounted for through the analysis of context. The SPAR-H method uses action and diagnosis as the major type tasks, and various error types are distinguished.

Error type—The term used in this report to refer to categories of human tasks. Other terms that are often used for this purpose are *error mode*, which is used in this report for describing specific human reliability analysis (HRA) methods (and then only when the method specifically uses that term), *task type*, and *error categories*.

Event—A high-level generic term encompassing a non-normal occurrence at a nuclear power plant (or other facility).

Human error—An out-of-tolerance action, or deviation from the norm, where the limits of acceptable performance are defined by the system. These situations can arise from problems in sequencing, timing, knowledge, interfaces, procedures, and other sources.

Human error probability (HEP)—A measure of the likelihood that plant personnel will fail to initiate the correct, required, or specified action or response in a given situation, or by commission will perform the wrong action. The HEP is the probability of the human failure event (ASME RA-S-2002).

Human failure event (HFE)—A basic event that represents a failure or unavailability of a component, system, or function that is caused by human inaction or an inappropriate action (ASME RA-S-2002).

Initiating event—In the SPAR model terminology, one of the high-level scenarios under study (e.g., steam generator tube rupture, loss of feed water, loss of offsite power, etc).

Joint HEP—In SPAR-H, a basic human failure event (HFE) that has both diagnosis and action parts. In preinitiator situations, this could include a task such as "trouble shoot and correct." A post-initiator basic event could include "operator recognizes the need to energize systems before implementing the correct configuration and then takes the appropriate action." The resulting basic event is then reviewed for dependency and modified accordingly.

Low power and shutdown (LP/SD)—A set of nuclear power plant (NPP) operating modes, determined by an individual plant's Technical Specifications (TS). However, most plants have adopted, or are in the process of adopting, the

NRC-approved Technical Specifications associated with the various plant vendors. In pressurized water reactors (PWRs), there are six operating modes. In LP/SD PRA, Modes 4, 5, and 6 (which are subcritical) are reviewed. Mode 4 refers to hot shutdown; Mode 5 refers to cold shutdown; and Mode 6 is associated with refueling. In a boiling water reactor (BWR), there are five operating modes. Modes 3, 4, and 5 refer to hot shutdown, cold shutdown, and refueling, respectively.

Negative PSFs—In SPAR-H, negative performance shaping factors (PSFs) are those PSF values that increase the nominal value rate, i.e., the PSF values are greater than 1, are referred to as negative PSFs and figure in conjunction with positive PSFs in the overall HEP calculation. When the number of negative PSFs is three or greater, then the HEP adjustment factor is applied.

Performance shaping factor (PSF)—A factor that influences human performance and human error probabilities is considered in the HRA portion of the PRA. In SPAR-H, this includes: *time available, stress/stressors, complexity, experience/training, procedures, ergonomics/ human-machine interface, fitness for duty,* and *work processes.*

SPAR-H method (1999 revision)—Standardized Plant Analysis Risk-Human Reliability Analysis method; second iteration of SPAR-H, with following characteristics: Action versus diagnosis task distinction, changes in performance shaping factor (PSF) definitions, influence factors and range of influence determined by review of literature and HRA methods.

SPAR-H method (2004 revision)— Standardized Plant Analysis Risk-Human Reliability Analysis method; third (current) iteration of SPAR-H, with following characteristics: Action versus diagnosis task distinction preserved, time influencing factor re-defined for low power and shutdown events, dependency refined, uncertainty calculation methods determined, ASME Standard for PRA requirements addressed, clarification on recovery presented, at power and LP/SD considerations made explicit.

Subtask—In this report, a human action at a level lower than a task (i.e., basic event) level. May also be called a subevent.

Task—In this report, often refers to the human action(s) described in a SPAR model basic event [e.g., failure to recover residual heat removal (RHR)]. The level of these tasks often encompasses relatively large numbers of human actions, which might, in other circles, be called tasks in their own right.

Unsafe Actions—Those actions taken or omitted that lead the plant into a less safe state. Only a subset of human errors result in unsafe actions. Also, only some portion of unsafe actions lead to human failure events defined in the PRA model. For example, timing and available barriers may limit the number of unsafe actions that become human failure events.

1. INTRODUCTION

1.1 Overview

The Standardized Plant Analysis Risk (SPAR) human reliability analysis (HRA) method is a simplified HRA approach intended to be used in conjunction with the development of SPAR probabilistic risk assessment (PRA) models. The language included in this document often refers to aspects of SPAR models such as initiating events and basic events—terms common to PRA. The glossary of this report presents general definitions for these terms. The SPAR-H method can also be used to support event analysis. This aspect of the method is reviewed in Section 4.2.4.

The process of carrying out HRA assumes that human error can be identified, modeled (represented), and then quantified. Guidance for satisfying these requirements, including the process for error identification of events for inclusion in PRA models, may be found in IEEE STD 1082 (1997) or the ASME Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications (ASME-RA-S-2002). We assume that the human error probabilities (HEPs) generated from the SPAR-H method will be used in PRA logic modeling structures, such as event trees and fault trees[2], so that there is a context regarding how these estimates are to be combined and their effects interpreted. Modifying failure probabilities based on dependency without regard to how the HEPs are to be combined can result in erroneous conclusions about their potential contribution to risk.

1.2 Background

The HRA approach presented in this document has its origin in some of the early U.S. Nuclear Regulatory Commission (NRC) work in the area of accident precursors (NUREG/CR-4674 1992). The PRA models developed under the NRC's Accident Sequence Precursor (ASP) program included aspects of HRA; however, the HRA involved was not developed fully. This specific method was designated the ASP HRA methodology. Although, this original approach was adequate for a first generation of SPAR models concerned with screening analysis, the NRC staff analysts decided that further refinement of the HRA method was warranted and that this effort should coincide with efforts underway to refine the SPAR models. As a result, the Idaho National Laboratory (INL) undertook a review in 1994, during which time a number of areas for improvement were noted. For example, in 1994 the ASP HRA methodology was compared on a point-by-point basis to a variety of other HRA methods and sources. A team of analysts at the INL evaluated the differences among the methods. This evaluation led to a revision of the 1994 ASP HRA methodology to incorporate desirable aspects of these other methods. In addition, the revision also focused on addressing user comments.

By 1999, the field of HRA had changed enough to cause the NRC to undertake a second revision to the ASP HRA methodology. A revised methodology, named the SPAR-H method, was developed, and ASP was omitted from the title. A revised form for applying the SPAR-H method, the SPAR Human Error Worksheet, was developed and underwent testing by NRC inspectors. After using the method for a period of time, a number of areas for improvement were identified. These included more refined concepts and definitions and suggestions for enhancing ease of use.

At that time, the NRC's Office of Nuclear Regulatory Research identified two further areas for refinement. The first refinement involved better assistance to the analyst, with understanding or estimating the uncertainty associated with HEP estimates produced with the method. As an artifact of the method's early reliance on error factors, analysts could routinely produce upper-bound probabilities greater than 1 when modeling strongly negative performance shaping factors

[2] A fault tree is used to depict how component level failures propagate to cause an undesirable system failure (event). The system level event is the top-event of the fault tree. Fault tree analysis offers a graphical tool for understanding all those combinations of component failures resulting in a specific system failure. It is also useful in understanding how a particular component failure can be the result of lower-level failures.

(PSFs). This problem was not unique to performing SPAR-H. Although HRA analysts have worked around this problem for 20 years, the INL was tasked to attempt to develop an easy-to-use but more suitable approach to representing uncertainty information for use in analysis with the SPAR models employing Systems Analysis Programs for Hands-on Integrated Reliability Evaluation (SAPHIRE) software (NUREG/CR-6618 2000).

The second refinement involved the applicability of this approach to support NRC-sponsored model development research in the area of low power and shutdown (LP/SD) risk analysis. Specifically, inquiry was made regarding whether the method, as configured, was easily applied to LP/SD scenarios. When the SPAR-H method was first developed, there were no SPAR models for LP/SD and, at that time, the HRA analysts had not considered LP/SD as constituting a separate class of events that could require either subtle or major adjustments to the method.

1.3 HRA Orientation

The goal of HRA is to support PRA in identifying and assessing risks associated with complex systems. PRA, in conjunction with HRA, affords analysts the ability to look at sequential as well as parallel pathways that generate risk, including the human contribution to that risk. Insights are gained by applying event frequencies to hardware failure models and reviewing expected frequencies for various hazardous end-states by condition assessments.

From the authors' perspective, HRA is performed as a qualitative and quantitative analysis. It helps the analyst to study human system interactions and to understand the impact of these interactions on system performance and reliability. The SPAR-H method is used to assist analysts in identifying potential vulnerabilities. The SPAR-H method can also be used to characterize preinitiating actions, initiating event-related actions, and postinitiating event interactions. The SPAR-H quantification is used because it is an efficient and not overly time consuming approach to representing human actions and decisions in the final SPAR analysis model. Although the SPAR-H method is used primarily in SPAR model development and as a part of the event analysis process performed by NRC staff, the method can also be used to support detailed screening analysis whose goal can be the exclusion of human interactions from more detailed and complex HRA analysis. The SPAR-H method differs from less detailed HRA in that it requires analysts to consider dependency and a defined set of PSFs when performing quantification. For example, analysts using techniques such as the Failure Likelihood Index Method (FLIM) or the Success Likelihood Index Method (SLIM) are free to include any number of PSFs that they think might apply. The SPAR-H method also differs from some of the earlier time-reliability curve (TRC) methods in that the SPAR-H method does not overly rely on time as the primary determinant of crew performance, but rather treats time as one of a number of important shaping factors influencing human performance.

SPAR-H also does not explicitly distinguish among skill-, rule- and knowledge-based behaviors. Extended TRC data collection encompassing 1,100 simulator trials failed to verify the independence of these definitions (see EPRI TR-100259, 1992).

1.3.1 Guidance in performing HRA

A number of guidance documents are available that can be used to support the SPAR-H method. These include the IEEE Guide for Incorporating Human Action Reliability Analysis for Nuclear Power Generating Stations (IEEE STD 1082, 1997), Systematic Human Action Reliability Procedure (SHARP; Hannaman and Spurgin 1984), and the ASME Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications (ASME RA-S-2002). The IEEE recommended practice for conducting HRA (IEEE STD 1574) is under development and when completed will also provide a framework for conducting HRA.

We assume that a number of principles suggested in these various references will be adhered to, including the following:

- Identify and define the scenario or issue of interest.
- Review documentation when possible, including event and near-miss databases,

procedures, and the Safety Analysis Report (SAR).

- Perform limited task analysis—walk down systems, conduct interviews, review appropriate training materials, and review videotape and crew simulator performance.
- Screen and document—build a qualitative model integrated with systems analysis.
- Quantify.
- Perform impact assessment.
- Identify and prioritize modifications to reduce risk.
- Document.

1.4 Organization

This report is archival, that is, it contains historical information regarding SPAR-H method development, as well as provides an overview, review of technical basis, and sample applications of the method. Section 1 presents the background and general HRA approach.

Section 2 details the information processing-based model from which the SPAR-H method was developed. Summary performance influencing factors are introduced; task and error types are defined; and the relation of SPAR-H PSFs to other HRA methods is discussed. The approach to dependency and uncertainty factors, including quantification, is also reviewed.

Section 3 summarizes and discusses the approach and compares this HRA method against some of the criteria for HRA, as defined by the new ASME PRA Standard, and the *PRA Procedures Guide for NASA Managers and Practitioners* (Stamatelatos and Dezfuli 2002). Last, this report contrasts the SPAR-H method against criteria developed by the authors for review of HRA methods (in Gertman and Blackman 1994).

Section 4 presents considerations when using the SPAR-H method, reviews application of the SPAR-H method to event analysis, and addresses use of the SPAR-H worksheets.

Section 5 presents consideration of PSFs for at-power and LP/SD scenarios, examines results of a sample application of at-power, and LP/SD approaches to a loss of inventory (LOI) scenario, and reviews base error rates for diagnosis and action tasks.

Appendices A and B present SPAR-H worksheets used to support the analyst application of the method to at-power and low-power/shutdown (LP/SD) scenarios. Appendices C and D present at-power and LP/SD examples, respectively. Appendix E presents SPAR-H results for dry cask risk assessment. Appendix F presents operational examples for the SPAR-H assignment of PSF levels. Appendix G shows the relative relationship among SPAR-H PSFs. Appendix H presents the SPAR-H development history. Last, Appendix I presents a compendium of SPAR-H review comments from external review and public meeting forums.

2. SPAR-H METHOD

2.1 Model of Human Performance

Models of human behavior are discussed in a variety of behavioral science sources that deal with cognition [see, for example, Anderson (1995); Medin and Ross (1996)]. The cognitive and behavioral response model developed for the SPAR-H method was developed out of early cognitive science approaches and is generally termed an information processing approach to human behavior. The factors constituting the basic elements of this model also come from the literature surrounding the development and testing of general information processing models of human performance. Most information processing models of human behavior include representation of perception and perceptual elements, memory, sensory storage, working memory, search strategy, long term memory, and decision making (see Sanders and McCormick, 1993).

Other psychological models or paradigms such as stimulus-response models have been developed to aid in understanding human behavior. In the stimulus-response approach much of cognition is not considered; rather, reflexive behavior is developed over time as a function of learned associations between human actions and rewards or punishments.

The SPAR-H model combines elements of the stimulus-response and the information processing approaches. This is because the HRA analyst needs to be able to consider aspects of diagnosis and planning as well as the likelihood of the operators' ability to successfully carry out actions often identified through procedures. This distinction between *diagnosis* (i.e., information processing) and *action* (i.e., response) is the basis for separate diagnosis and action worksheets, contained in Appendices A and B, with separate probability calculations.

SPAR-H also acknowledges the role of environmental factors upon diagnosis and action. For example, during evaluation of performance shaping factors, analysts note whether interactions might be difficult to analyze due to misleading indications, complexity, time-dependent aspects, and the effects of combinations of unavailable or faulted equipment. Components of the SPAR-H behavioral model approach, presented in Figure 2-1, are discussed below.

Information flow from the environment can be across different sensory modalities: visual, auditory, and kinesthetic. Environment factors can act to *filter* this information. Perhaps the easiest example of this is how noise in the environment can operate to mask the strength of an annunciator. Equipment response characteristics can also alter the strength or nature of available sensory information. This is present in phenomena such as

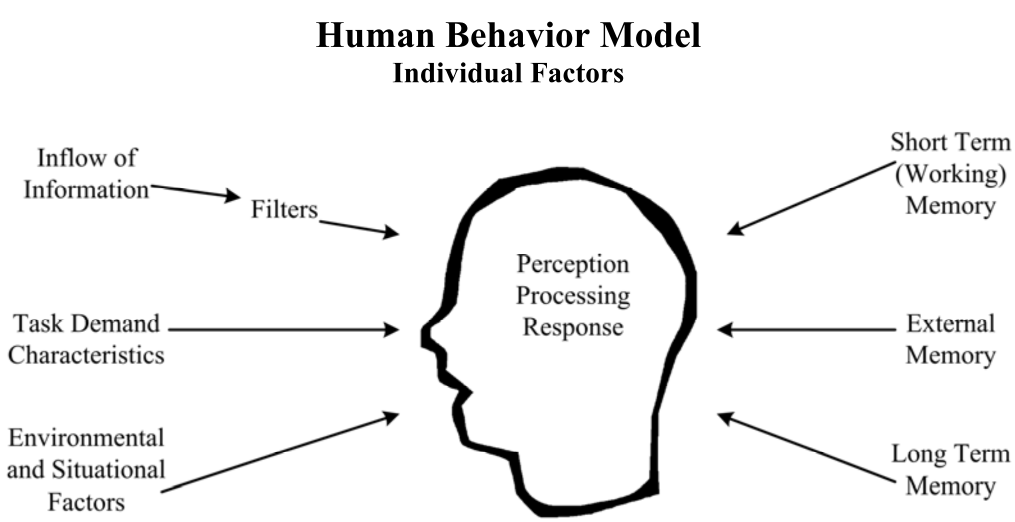

Figure 2-1. Human Performance Model.

speech clipping when using certain types of communication equipment. Still other filters internal to the operator exist as well. These include the influence of language, experience, and expectancies.

Perception can be simple and direct. We refer to this as detection. An example is when an operator detects that a low level alarm has actuated or detects that there is a change in a trend plot or other charting device. This perception acts as a bridge between physical sensation and cognition. Aspects of detection include identification and recognition, which are also influenced by these filters. Bodies of research have focused upon detection under different conditions. The more well known of these are referred to as studies in signal detection and are reflected in signal detection theory. Other research in the behavioral sciences has examined the role of experience, learning, training, and beliefs upon perception and perceptual processes. SPAR-H incorporates these mechanisms at a very high level via the assignment of performance shaping factors.

Aspects of high order information processing present in the SPAR-H approach consist of short term, external, and long term memory. McCormick and Sanders (1993) view the human memory system as being based upon three processes. These are *sensory storage*, *short term memory*, and *long term memory*. These processes work on two types of memory systems, auditory and visual. Evidence on the existence of these two distinct sensory memory systems is reviewed in Anderson (1995). He notes that there is an iconic memory for visual information processing and an echoic memory for auditory processing. SPAR-H acknowledges these components of memory but does not model them explicitly as part of the HRA process.

For a through review of this area of human performance the reader should refer to Anderson (1995). For example, existence of a brief visual sensory store can be traced back to Sperling's research in the early 1960s. In the underlying SPAR-H model, short term memory can be construed as the ability of the operator to keep a limited amount of information in an active mental state. Long term memory items must be activated and retrieved. The capacity of short term memory can vary depending upon whether meaningful information can be chunked, i.e., grouped, or not. We tend to view short term memory as a process through which information is available for use by cognitive processes. Hence, both long term and short term memory play a role in a human information processing model.

Short term memory has been reinterpreted by others. For example, Shallice (1982) describes a supervisory attention model with limited capacity that is directed toward cognitive tasks such as decision making and planning, and where attentional resources are directed on the basis of the degree to which the task involves novel or technically difficult situations such as those where strong habitual responses or behaviors may be inappropriate. Baddeley (1990) describes a working memory model that includes a central executive similar to the Shallice model. This central executive invokes, directs, and integrates processing routines with supervisory attention phenomenon described in Shallice (1982). Baddeley's expanded model includes a visual sketchpad component that enables temporary storage and manipulation of spatial and visual information. There is also a phonological loop, which is responsible for manipulation and temporary storage of auditory/verbal information. The SPAR-H underlying model is a simplified memory framework akin to the Anderson (1995) approach. It may, however, also be interpreted according to the more detailed model of human memory documented in Baddeley (1990) and others.

The SPAR-H model also includes *external memory*, which consists of information that a person may use to aid their short and long term memory. Examples of external memory are the different types of operating procedures, in which the steps of a task are enumerated for reference by the operator. The operator does not need to retain this information in short or long term memory. Rather, the information is available to reference whenever the operator needs it. In SPAR-H, external memory is modeled as the performance shaping factor for procedures.

Demand characteristics of the task impact the internal resource requirements of the operator. For example, tasks that require the operator to perform mental calculations or maintain multiple hypotheses while keeping track of other tasks or to perform monitoring functions reduce the available mental resources, thereby leading to error. High demand has been shown to interfere with recall. Physically demanding tasks can also deplete internal resources, producing fatigue that can result in higher than expected human error for physically demanding and cognitively demanding tasks.

Environmental and situational factors are contributors to the success or failure of human performance via their impact upon perception, processing, and response. High levels of complexity, e.g., ambiguous problems involving multiple faulted systems, more than one solution, and producing unsuspected interactions, can result in cognitive overload where perception, processing and response are compromised. High complexity interferes with short term and long term memory components. For example, system relationships may be relatively complex, and the configuration and flow of events are not well recognized. The operator may not be able to recognize the true nature of the problem and, thus, is challenged to determine a solution from memory. In this situation, it would be more difficult to determine what was occurring and to take the correct course of action. The SPAR-H analyst represents complexity and directly by assignment of the appropriate PSF level. Higher levels of complexity are assumed to be associated with greater human error.

Table 2-1 presents operational factors in SPAR-H that are mapped to the information and behavioral model discussed above. Review of the behavioral sciences literature reveals eight summary operational factors, or PSFs, associated with nuclear power-plant operation. These operational factors can be directly associated with the model of human performance. Within the table, various aspects of performance and their relation to the PSFs are indicated. For example, perception is limited based upon human sensory limits, is susceptible to disruption or interference, and occurs as a function of modality (auditory, visual, or kinesthetic). Perception by operators is often a function of the quality of the human machine interface (HMI).

Working memory and short term memory model aspects are based upon factors including capacity, rehearsal, and attention. Memory capacity is physically fixed, but training can make operators more effective at chunking information, thereby increasing the storage efficiency of memory. Rehearsal refers to the use of memorization, training, and operations experience, which can aid in the speed and ease of retrieving memories by keeping information active in memory. Attention is directed and influenced by stress, task and environment complexity, experience, and training. Attention is further directed by procedural cues.

For example, procedures, determined to be an influencing factor in operating events, also have a basis in information processing as an external memory aid. Procedural errors or inadequacies in format and lack of appropriate cautions or warnings can increase the likelihood of human error. Lack of procedures or manuals can directly increase this likelihood. In the past, procedure problems, such as assumptions by the procedure writers that discharge high-pressure injection (HPI) pressures would be available to control room personnel when they were not contributed to decrements in human-system performance (e.g., the Oyster Creek event in U.S. NRC 1992). Procedures also can interact with other work practice factors such as quality assurance or training. For example on May 3, 1997, during the shutdown process at Oconee Nuclear Station, Unit Three (U.S. NRC 1997), a single reference leg for both channels of the let-down storage tank (LDST) instrumentation was being used without caution in procedures for common cause failure. This contributed to a reactor trip. Also, procedural inadequacies in place at the time allowed for the LDST level to be maintained in a range lower than the alarm setpoint.

Evidence for the importance of workload in human performance has been established through the use of primary task measures and secondary task measures. At first, psychological studies used the relatively crude time reliability approach used in First Generation HRA. Workload was defined in terms of the ratio of the time available to the time required to perform a task. It was soon realized that this approach fails to distinguish between tasks that can be successfully time-shared and

Table 2-1. Operational Factors in SPAR-H

(The numbers after each entry refer to the PSF list at the bottom of the table.)

Inflow and Perception	Working Memory/ Short-term Memory	Processing and Long-term Memory	Response
Presence[6,3] (is the signal there?) and opportunity (is anyone present to receive the signal?) Human sensory limits[2,5,7] Modality [6,5] (verbal, graphic/symbol, text) • echoic • iconic • kinesthetic Interference [6,5,4,7] (signal, noise)	Limited capacity[5] *Serial processing *Good only for a short time [2,3,5,4] (20 seconds) Right amount of attention [2,3,4,5,7] required Rehearsal [2,3,5,7] Physical and mental health [7]	Training[4] (models, problem solving, behaviors) • learning Experience[4] (models, problem solving, behaviors) • learning Culture [8] (societal, organizational, interpersonal, (crew)) • learning Intelligence/cognitive skills[3,4,1,5,7] (decision making, problem solving) Interference factors [6,2,3, 7] (distraction) Available time [1,3] Physical and mental health [7]	Training (actions) [4] *Existing models of behavior *Practice and skill Experience [4] (actions) • practice and skill • existing models of behavior Proper controls available[6] Human action limits[6,7] (physical strength and sensory acuity) Ergonomics of controls[6,3] complexity Environmental degradation[2,3,6] Time to react versus time available [1]

Performance Shaping Factors

Available time[1]
Stress and stressors [2]
Complexity [3]
Experience and training [4]
Procedures (including job aids)[5]
Ergonomics and human-machine interface[6]
Fitness for Duty[7]
Work processes[8]

Note: Available time, from the operator's perspective, is influenced by information complexity, which can take more processing and reduce the time available to act.

those that cannot. Nor does it account for multiple resources (both internal and external to the operator) or explain how situations could exist where the performance was identical and yet the one task was more demanding. Research in secondary task performance, as a means to assess spare capacity on the part of subjects, has been used to assess the workload associated with performance on the primary task. Although large numbers of studies have used subjective measures to assess stress, physiological measures have also been used to assess the stress associated with mental workload. There is ample evidence of workload influence on performance.

The SPAR-H approach acknowledges the role of workload in influencing performance in a quantitative way through PSF assignment to complexity and stress. Generally speaking, the effects of physical workload such as having to perform multiple tasks, complete tasks more quickly, or move objects of increasing weight are captured under the PSF for stress and stressors; the effects of cognitive workload such as having to perform additional calculations, refer to multiple sources of information to verify readings, or co-ordinate actions based upon periods of waiting are captured under complexity.

In general, the SPAR-H model is a structural model for guiding analysis as opposed to a mathematical model of human information processing. The SPAR-H basic information-processing model can be used to aid conceptualizing the key aspects of an information-processing model of human performance, which reflects psychological principles. The purpose of beginning with this model is to account for and integrate the factors key to human performance when performing SPAR-H analysis.

In addition, these operational factors can be linked to the portion of the human information-processing model with which they are associated. The relation of summary factors to information processing model parameters is presented in Table 2-1. The model is also useful in terms of presenting the basis for how operational factors impact performance. Definitions of these eight PSFs follow in Section 2.4.4.

2.1.1 The Role of Work Processes

Work processes are present in the model described above in terms of the management and administrative environments parameter of the model and are present in the "work processes" PSF included in the SPAR-H worksheets (Appendices A and B). The influence of work processes in operating events has been recently highlighted. For example, a review of 37 operating events at U.S. commercial nuclear power plants (NPPs) from 1991 through 1999, conducted for the NRC's Office of Nuclear Regulatory Research, revealed a number of instances where work processes affected crew demands during operating events (Gertman et al. 2002). The errors and failures that occurred in these events included deficiencies related to design and design change work practices (81%), inadequate maintenance practices and maintenance work controls (76%), and corrective action program inadequacies (38%).

Work process factors were also implicated at the Dresden 3 event, May 15, 1996 (US NRC 1996), where failure of a feedwater regulating valve led to a reactor trip. Work process involvement in this event includes: inadequate inspection frequency of the feedwater regulating valve, and failure to challenge generic work package inadequacies. Failure of the PCS relay was attributed to licensee failure to trend repair information, inordinate delay to placing FRV back into service, and failure to follow industry practices resulting in control switches being in the wrong position prior to resetting Group 1 isolation.

Recently, the root cause analysis report for documenting the degradation of the reactor pressure vessel head corrosion incident at Davis Besse (2002) identified a number of work process or organizationally bound factors that may have contributed to the event. Implicated were a flawed boric acid corrosion control program, and subsequent failures such as lack of written evaluations, inadequate implementation of utility corrective action program, and lack of safety analysis for identified conditions. The root cause team also concluded that there was failure to take actions for identified adverse conditions, failure to trend, and failure to provide adequate training to personnel. These factors point toward inadequate work processes and inadequate implementation of work processes. See also the Augmented Inspection Team Report (U.S. NRC 2002).

For a more in-depth review and approach to work process evaluation, see Weil and Apostolakis (2002) who present a series of work process parameters and modeling approach to work process issues.

2.2 Task Types

The 1994 ASP HRA methodology divided tasks performed by personnel into two components, the processing component and the response component. Comments received from those trying to implement the method indicate this "processing and response" delineation was understood by human factors and HRA professionals working on the method but proved difficult for trainers, operators, and inspectors who were collaborating on its application.

In 1999, these components were renamed in the SPAR-H method as "diagnosis" and "action." Comments received suggested that this separation of task types was more easily understood. This represents a top-level distinction between tasks that are often used in HRA (some applications also classify actions as preinitiator, initiator-related, or postinitiator).

Within comments and task description fields of the SPAR-H worksheets, the SPAR-H method allows analysts to use more complete descriptions for tasks. However, quantification is based on the assignment of tasks to one of two types, diagnosis or action. In some ways, this simple delineation is close to THERP in how it assigns tasks to support quantification. When using this approach, activities such as planning, intra-team communication, or resource allocations during event progression are considered diagnosis.

When using SPAR-H, the analysis team makes decisions regarding the assignment of a particular post- or preinitiator activity to either diagnosis or action.

2.2.1 Guidance for Diagnosis

Guidance for diagnosis has to do with attributing the most likely causes of the abnormal event to the level required to identify those systems or components whose status can be changed to reduce or eliminate the problem. It includes interpretation and (when necessary) decision making. Diagnosis tasks typically rely on knowledge and experience to understand existing conditions, plan and prioritize activities, and determine appropriate courses of action.

When answering the question "Does this task contain a significant amount of diagnosis activity?" one should consider whether the operator or crew has to expend mental energy to observe and interpret what information is present (or not present), determine what that means, think of possible causes and decide what to do about it. The greater the amount of observing, interpreting, thinking and deciding the operator or crew performs, the more significant the amount of diagnosis activity that is taking place.

2.2.2 Guidance for Action

Guidance for action has to do with carrying out one or more activities (e.g., steps or tasks) indicated by diagnosis, operating rules, or written procedures. Examples of action tasks include operating equipment, performing line-ups, starting pumps, conducting calibration or testing, carrying out actions in response to alarms, and performing other activities during the course of following plant procedures or work orders.

2.2.3 Guidance for Diagnosis and Action

In performing HRA, it is sometimes practical and reasonable to model on the basic event level a task or subtask containing aspects of both diagnosis and action. In these situations, both diagnosis and action portions of the HRA worksheet are to be applied. For example, consideration of the task "*operator terminates loss of inventory (LOI) during LP/SD*" as part of the event tree for LOI should be modeled as a joint HEP. In order to terminate loss of inventory, the operator or crew must *diagnose*, that is, identify the leak path (the difficulty of which may vary, depending on whether the operators in the control room contributed to plant conditions and can simply retrace their steps to observe the error or whether actions independent of the control room contributed to the leak path and are more challenging for the operators to determine). The subsequent action(s) to be taken, either inside or outside the control room, are then evaluated on the worksheets. Both the diagnosis and action elements of the task are then quantified as part of the SPAR-H HEP determination process.

In a number of situations, arguably there will be a dependency between the diagnosis and action elements representing a single basic event. In SPAR-H, the intradependency within a single basic event consisting of action and diagnosis is acknowledged when combining (adding) these two elements to yield the composite or joint HEP, i.e., basic event value. Interdependencies between previous and subsequent basic events (HEPs) are calculated according to the dependency portion of the worksheet in Appendixes A and B.

In order not to be overly conservative, SPAR-H suggests that analysts use the HEP adjustment formula when calculating the HEP for those situations where at least three HEPs are determined to be nonnominal and negative (i.e., the value of the PSF is greater than 1). Review of the dependency assignment process is presented in subsequent sections of this document.

In general, there are better-established HRA data and data sources for actions than there are for diagnosis and planning activities. If cognitive activities are modeled and quantified with the SPAR-H method and determined to pose a significant contribution to risk, then analysts' evaluations should employ a more detailed HRA method. These methods include: a technique for human event analysis (ATHEANA; NUREG-1624 2000); Methode d' Evaluation del' la Reaslisation des Missions Operateur pour la Surete' (MERMOS; Bieder et al. 1999); or the connectionism approach to human reliability, (CAHR) Strater (2000). Where available, the EPRI ORE/Cause Based Decision Tree (CBDT) Method (EPRI TR-100259, 1992) may also be consulted. In subsequent sections of this report, these methods are discussed briefly and compared with the current SPAR-H method.

If the SPAR-H method is being used to evaluate a basic event consisting of multiple actions and decisions, such as is often the case with SPAR models, both diagnosis and action worksheets apply. Tasks that are proceduralized actions not requiring diagnosis are evaluated on the action task worksheets. When comparing PSFs among HRA methods, INL matched specific PSFs based upon appropriate diagnosis and action distinction components is reflected in the two comparison matrices developed (one for diagnosis, one for action). These matrices are presented in this report.

If any PSFs, either from the 1994 ASP HRA method or from the other HRA methods, did not match, they were noted. The team reviewed these nonmatching PSFs and other observations from the initial, nonquantitative comparison process, and used this information to assist in developing the SPAR-H method and associated PSF definitions. The objective for the completed version of the SPAR-H method was to cover the important shaping factors noted in these methods. These PSFs are present in the human performance model presented in Section 2 (Figure 2-1).

2.3 Error Types

In a manner similar to the PSF matching performed as part of the SPAR-H method development process, the base error types from the other HRA methods were compared with the 1994 ASP HRA method error types. This comparison was considerably easier than the PSF matching. It was easier because it was straightforward to judge whether or not other error types corresponded to either or both of the processing and response error types of the 1994 ASP HRA method, as well as the new terminology (diagnosis or action). Early versions of the ASP HRA method attempted to differentiate between errors of omission and errors of commission. Experience demonstrated that this distinction was not useful in making more accurate predictions of error.

Therefore, for the base failure rates(s) for diagnosis and action, the SPAR-H method uses a composite rate for omissions and commissions. Since the first ASP HRA method screening version, the discussion of omission and commission within the HRA community for describing error has slowly moved toward such terms as *slips*, *lapses*, and *mistakes*. This, in part, is due to intuitively appealing evidence that there is an important difference between slips and mistakes, the two frequently discussed errors of commission.

The first type of commission is properly called a slip (i.e., right intention but wrong execution); the second is called a mistake (i.e., having a wrong impression of what to do coupled with an improper action or decision). Review of the context will help the analyst to determine whether slips or mistakes are more likely and whether these errors are likely to have common cause implications. Most second-generation HRA approaches now emphasize that context, that is, combinations of PSFs, plant conditions, and situational factors function together as a major determinant of mistakes. The PSF emphasis in the SPAR-H method is intended to reflect incremental progress and direction in contemporary HRA.

Thus, it is equally important, from a screening perspective, to be able to address PSFs that are assumed to contribute to context, as it is to distinguish among a slip, lapse, or a mistake. From a methodological perspective, it is important to emphasize that the HRA analysis team needs to follow an approach that systematically identifies those errors likely to result in unsafe acts, evaluates the influence of major PSFs, and estimates their probability of occurrence.

The composite approach used in SPAR-H is also believed to encompass other error taxonomies. For example, the nonuse of available information and the incorrect use of available information as described by Hacker (1986) are assumed to be covered by the nominal rate. The presence of technically inaccurate information is covered as well, and indicated by adjustment of the human system interaction (i.e., ergonomics/HMI PSF). During the error identification phase of the PRA/HRA process, nonroutine, significant errors of commission that represent operator or crew mistakes should be considered for explicit modeling and quantification by the risk analyst.

2.4 PSFs

Many, if not most, HRA methods use PSF information in the estimation of HEPs. In general, PSF analysis enhances the degree of realism present in HRA analysis. The extent and resolution of PSF analysis should only be specific enough to identify potential influences and rate them on the corresponding SPAR-H worksheets. Historically, the first use of PSFs in HRA to modify nominal or base failure rates is documented in THERP. The current generation of HRA methods, often referred to as second-generation HRA, also uses PSF information in one form or another when calculating HEPs. When assigning the PSF level, the analyst evaluates the PSF from the perspective of the operator. Thus, the analyst would evaluate the complexity of the diagnosis or action required for a scenario or range of scenarios from the perspective of the operator as opposed to the analyst's view of the complexity as a whole.

In 1999, changes to the ASP/SPAR HRA method were implemented. The changes made at this stage were in error type, PSFs, and in their definitions. For example, the definitions associated with the performance shaping factors became more expansive in nature to cover aspects of PSFs being recognized in other methods. Also, some methods distinguished between PSFs that were represented by a single PSF in the SPAR-H approach.

The changes were made based on field-testing and indicated that:

- "The raters don't understand the processing/ response dichotomy"
- "Most of the other HRA methods recognize separate diagnosis and action error types"
- "Other HRA methods have organizational factors as a PSF."

In 1999, changes were also made to ensure the SPAR-H method was as broad in coverage as possible. Once the changes in error types and PSFs were made, new lists were created for error types and PSFs. Eight PSFs were identified: available time, stress and stressors, complexity, experience and training, procedures, ergonomics and human-machine interface, fitness for duty, and work processes. These same PSFs are present in the 2004 version; they differ only in terms of their description.

Next, comparison matrices were created (one for the new diagnosis error type, one for the new action error type) that compared PSFs and their weight multipliers for SPAR-H method PSFs

Table 2-2. HRA methods used in SPAR-H comparisons.

HRA Method	Date	Authors	Focus - Purpose
CREAM[1]	1998	E. Hollnagel	Human performance classification based on error modes and consequences (phenotypes) and causes (genotypes). Uses simple Contextual Control Model (CoCoM) of cognition that includes continuous revision and review of goals and intentions. Assesses cognitive function failures and common performance conditions (CPCs) to support failure rate estimations.
HEART[2]	1988	J. Williams	HRA based on nine generic tasks with individual nominal error rates. Analysts identify error-producing conditions (EPCs). EPCs operate as multipliers to increase base failure rates; their basis is in the behavioral sciences literature.
THERP[3]	1983 NUREG/CR-1278 [Developed in the 1970s and refined in early 1980s].	A.D. Swain and H.E. Guttmann	Developed to provide representational modeling of human actions (HRA Event Trees) and estimation of HEPs. Emphasis is on nuclear power plant applications to support PRA Provides HEP tables based on data gathered from various domains.
ASEP[4]	1987 NUREG/CR-4772	A.D. Swain	Developed to provide an efficient method for estimation of screening HEPs for pre- and post-accident human actions. Based on THERP.
SHARP1[5]	1990	Wakefield, et al	Developed to provide a consistent approach to HRA assessments. Contains performance shaping factor information. Addresses pre- and post initiator conditions. Revision to early work in this area under the same name.

[1]Cognitive Reliability and Error Analysis (CREAM) Method.
[2]Human Error Analysis and Reduction Technique (HEART).
[3]Technique for Human Error Rate Prediction (THERP).
[4]Accident Sequence Evaluation Program (ASEP) Human Reliability Analysis Procedure.
[5] Systematic Human Action Reliability Procedure (SHARP1)

Table 2-3. Action PSF Comparison Matrix, at power (PSFs = 8).

SPAR-H PSFs	SPAR-H PSF Levels	SPAR-H Multipliers	HEART Multipliers	CREAM Multipliers	ASEP Multipliers	THERP Multipliers
Available Time	Inadequate Time	***P(failure) = 1.0***			**P(failure) = 1.0** - Table 7.2	**P(failure) = 1.0** - Table 20.1
	Time available = time required	**10**	**11** - EPC	**5** - CPC 20	**10** - Table 7.2	**10** - Table 20.1
	Nominal time	**1**	1	**1** - CPC 19	**1** - Table 7.2	**1** - Table 20.1
	Time available ≥ 5 x time required	**.1**				
	Time available > 50 x time required	**0.01**		**0.5** – CPC 18	**0.01** -Table 7.2	**0.01** - Table 20.1
Stress/ Stressors	Extreme	**5**			**5** -Table 7.3	**5, 25** - Table 20-16
	High	**2**	**1.3** - EPC 29 **1.15** – EPC 33	**1.2** – CPC 22		**2, 5** - Table 20-16
	Nominal	**1**		**1** – CPC 21		
Complexity	Highly complex	**5**	**5.5** – EPC 10	**2** – CPC 17	**2.5 or 5** (depending on stress)	
	Moderately complex	**2**		**1** – CPC 16		
	Nominal	**1**		**1** – CPC 15		
Experience/ Training	Low	**3**	**17** – EPC 1 **3** – EPC 15 **8** – EPC 6 **6** – EPC 9 **4** – EPC 12 **2.5** – EPC 18 **2** – EPC 20 **1.6** – EPC 24	**2** – CPC 25	**10** -Table 8.3	**2** - Table 20-16
	Nominal	**1**	**1**	**1** – CPC 24	**1**	**1**
	High	**0.5**		**0.8** – CPC 23	**0.1** - Table 8.3	
Procedures	Not available	**50**			**P(failure) = 1.0** - Table 7.1, Table 8.1	**50** - Table 20.7

Table 2-3. (continued).

SPAR-H PSFs	SPAR-H PSF Levels	SPAR-H Multipliers	HEART Multipliers	CREAM Multipliers	ASEP Multipliers	THERP Multipliers
	Incomplete	**20**	**5** – EPC 11 **3** – EPC 16,17 **1.4** – EPC 28 **1.2** – EPC 32 repeat	**2** – CPC 14		**10** - Table 20-7
	Available, but poor	**5**	**5** – EPC 11 **3** – EPC 16,17 **1.4** – EPC 28 **1.2** – EPC 32 repeat	**2** – CPC 14		**10** - Table 20-7
	Nominal	**1**		**1** – CPC 13		
Ergonomics/ HMI	Missing/Misleading	**50**			**P(failure) = 1.0** - Table 7-1, 8-1	**100, 1000** - Table 20-12
	Poor	**10**	**10** – EPC 3 **9** – EPC 4 **8** – EPC 5, 7 **4** – EPC 13, 14 **2.5** – EPC 19 **1.6** – EPC 23 **1.4** – EPC 26 **1.2** – EPC 32 repeat	**5** – CPC 11 **2** – CPC 7		**6** - Tables 20-9, 11, 12 **10** - Tables 20.10, 13, 14
	Nominal	**1**		**1** – CPC 9, 10, 6		
	Good	**0.5**		**0.8** – CPC 5 **0.5** – CPC 8		

Table 2-3. (continued).

SPAR-H PSFs	SPAR-H PSF Levels	SPAR-H Multipliers	HEART Multipliers	CREAM Multipliers	ASEP Multipliers	THERP Multipliers
Fitness for Duty	Unfit	***P(failure) = 1.0***				
	Degraded Fitness	**5**	**1.8** – EPC 22 **1.2** – EPC 30 **1.1** – EPC 35			
	Nominal	**1**				
Work Processes	Poor	**2**	**2** – EPC 21 **1.6** – EPC 25 **1.4** – EPC 27 **1.2** – EPC 31 **1.06** – EPC 36 **1.03** per add'l man – EPC 37	**5** – CPC 29 **2** - CPC 4 **1.2** – CPC 3 **1** - CPC 28		
	Nominal	**1**		**1** – CPC 2,27		
	Good	**0.8**		**0.8** – CPC 1 **0.5** – CPC 26		

versus PSFs and multipliers for other contemporary HRA methods. These results are presented in Table 2-2.

As part of this PSF comparison process, four contemporary PSF-intensive methods were selected by HRA analysts for comparison. These other methods were HEART, CREAM, accident sequence evaluation program (ASEP) and THERP. Only one, ASEP, approximates a screening level approach. The others may be used to support a detailed HRA analysis. The comparison between the SPAR-H method and individual HRA methods is presented in Table 2-3. A discussion of this comparison follows.

2.4.1 PSF Comparison Findings

For available time, the SPAR-H method covers the entire influence range accounted for by the other methods. For example, only ASEP, THERP, and the SPAR-H method assign a failure probability of 1 when there is inadequate time available for crew response. In terms of the lower bound, the SPAR-H method assigns a multiplier of 0.01 for instances where the time available is greater than 50 times the average time required to perform the task. This also is comparable with multipliers used by ASEP and THERP. CREAM allows a reduction in the failure rate when additional time is available, but only by a factor of 0.5. In addition, CREAM assigns its weighting factor by selecting one of three common performance conditions (CPC 18, 19, or 20).

Extreme stress in the SPAR-H method is assigned a multiplier of 5. This value is higher than those suggested by either HEART or CREAM and precisely the same as ASEP. However, it is less than the multiplier of 25 permissible under THERP for instances when the cognitive state of the crew is such that they believe themselves to be in a life-threatening situation. In the SPAR-H method, it was determined that the majority of scenarios to be reviewed would represent potential situations where the extent of stress experienced would be less than life threatening. All five approaches used a lower bound (i.e., multiplier of 1) to represent nominal conditions.

Only the SPAR-H method and CREAM differentiate among nominal, moderate, and high complexity situations' potential influence on performance. The SPAR-H method assigns a multiplier of 5 for complex situations, whereas HEART assigns 5.5, and CREAM a 2. THERP does not treat complexity as a separate PSF. However, recent methods such as CAHR (Strater 2000) point out the importance of this PSF as a determinant of behavior.

Experience and training effects are well documented in the behavioral sciences and training literature. The range of effect for this particular PSF is relatively large, ranging from 2 to 10 for instances representing various degrees of training inadequacy. For situations where above average training has been implemented, the effect of this PSF ranges from 0.5 (SPAR-H method) to 0.1 (ASEP, Table 8.3). Neither THERP nor HEART have multipliers for situations where experience and training is highly positive.

In the SPAR-H method, an absence of procedures has a pronounced effect. The base failure rate is multiplied by a factor of 50. ASEP assigns a failure probability of 1. THERP also assigns a multiplier of 50. CREAM and HEART have no explicit assignment for situations wherein procedures are not available. Since there are many instances of personnel performing noncontrol room activities without procedures, the assignment of 1 used in ASEP seemed overly severe. Therefore, the SPAR-H method endorses the THERP guideline for performance in the absence of procedures.

For the ergonomics and human-machine interface category, missing or misleading indication warrants a multiplier of 50 (SPAR-H method). ASEP and THERP have a more severe adjustment, ranging from a factor of 100 (THERP) to complete failure (ASEP). The SPAR-H method assigns a multiplier of 10 for situations involving poor ergonomics, as does HEART and THERP (Table 20.10). CREAM limits the influence of poor ergonomics to a multiplier of 5, and ASEP does not deal with it specifically.

Fitness for Duty is present explicitly as a PSF only in the SPAR-H method and HEART. Fitness for duty was included in the SPAR-H method because of its appearance as a factor in a number of operating events and also based on the uncontested behavioral sciences research on the negative impact of illness and circadian upset, including sleep deprivation, on human performance.

Poor work processes is present as a PSF category in the SPAR-H method, HEART, and CREAM. Both CREAM and the SPAR-H method assign a multiplier of 5 in instances where work processes are poor. HEART has six different error producing conditions in which poor work processes are included. The highest multiplier available to the analyst is 2.0. CREAM also has four different common performance conditions with which poor work processes are associated. Only CREAM and the SPAR-H method assign a 1 for nominal conditions for work processes, and both the SPAR-H method and CREAM allow for base error probabilities to be reduced by a factor of 0.5 for instances where work processes are established as good.

2.4.2 PSF Changes

PSF changes were driven by several considerations. The first consideration was consonance with the other methods. SPAR-H PSF information tables were presented at a meeting with the NRC on December 2, 1998. Based on comments from that meeting, final adjustments were made to the PSFs, the PSF weights, and the PSF definitions.

The second consideration was a desire to achieve realistic values while maintaining as much of the 1994 ASP HRA values as possible. These values had been validated by application review by inspectors, SPAR model analysts, and HRA practitioners. Following the update to the SPAR-H method, SPAR-H method base failure rates were compared with base failure rates associated with the various HRA methods. A certain amount of analyst judgment was required, since many of the error types in the other methods incorporated one or more PSFs. For example, the HEART error type, “Shift or restore system to a new or original state on a single attempt without supervision or procedures,” incorporates aspects of the procedures PSF and the work processes PSF. In instances where it was not easily possible to determine a base rate from a composite rate, another HEP or base rate was used. The rates compared favorably and no change to the 1994 ASP error rates for diagnosis and action tasks was necessary. Further discussion of base rate comparisons is presented in Section 3 of this report.

2.4.3 Relationship of PSFs to HEPs Underlying the SPAR-H Method

The basic human information processing model and its relation to PSFs is presented above in this report. The second major component in the SPAR-H method is the relationship of PSFs to HEPs. The third component, the SPAR-H method’s approach to uncertainty analysis, is presented below in this section.

Unlike most HRA methods, the SPAR-H method recognizes that a number of PSFs may have both a positive and negative effect on performance. For example, training is well understood to influence performance both positively (when training emphasizes the appropriate learned responses) and negatively (e.g., when training is misleading or absent). In other HRA methods, positive effects on PSFs are typically limited to the influence of time on task performance reliability. CREAM does make allowance for the positive influence of time, training, and work processes PSFs upon performance. HEART addresses mainly the detrimental effects of PSFs on performance reliability.

The SPAR-H method assumes that most PSFs have positive effects that should be accounted for in the estimation of the HEP. The SPAR-H method also assumes that these positive effects may often be a reflection of the function of the negative effects of the PSF on performance. As shown in Figure 2-2, error probability increases as the negative influence of the PSF grows. Conversely, error probabilities diminish as the positive influence of the PSF grows until some lower bound is reached. Note that PSFs have a significant effect on prediction of performance reliability (see Figure 2-2). For example, an objective measure of fitness for duty may be the time (in hours) since lack of sleep, which has a variable influence on the performance of different people. This is shown by the distributions parallel to the HEP axis. The SPAR-H method models the uncertainty of the HEPs at each objective level of a PSF as a beta function.

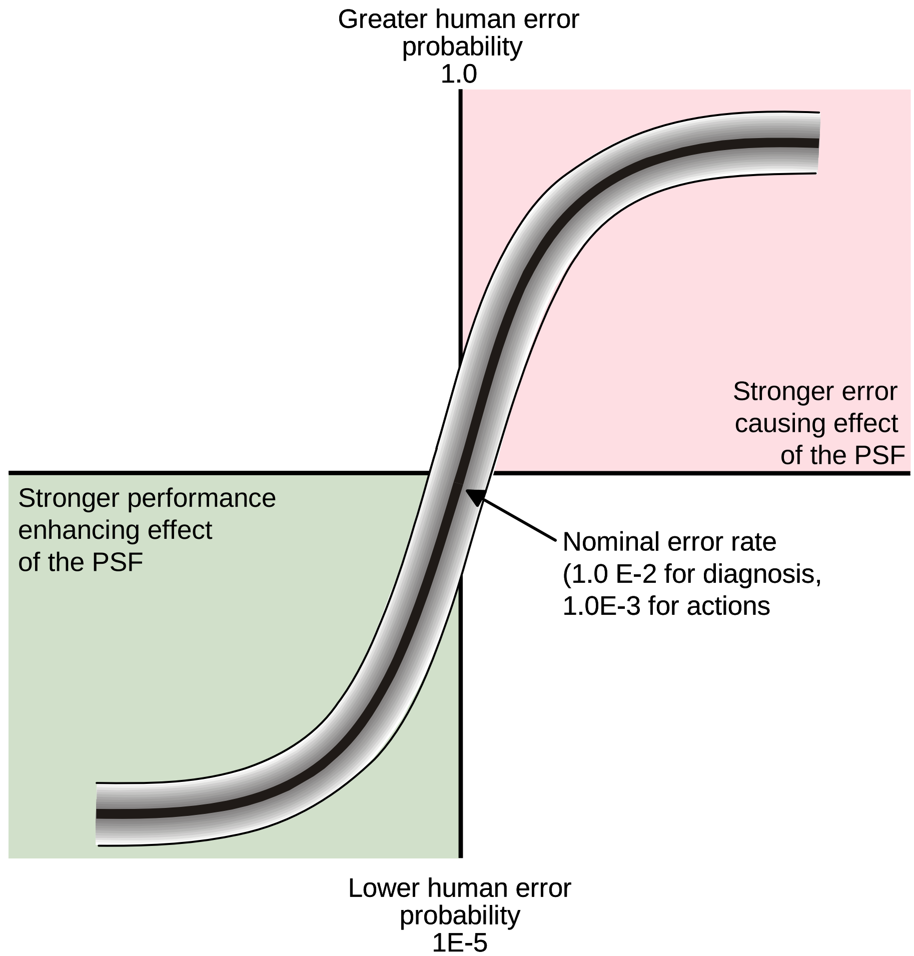

Figure 2-2. Ideal mean HEP as a function of PSF influence.

Some knowledge (i.e., limited or imperfect) of the actual shape of the individual PSF distributions is available, which therefore are presented as hypothetical distributions to aid the reader in conceptualizing the model. Composite distributions for PSFs are assumed to be the same as that for any individual PSF used in the method. However, little is known about composite influences of PSFs.

It is also assumed that the uncertainties associated with PSFs affect some portion of the uncertainties of the HEP. Uncertainty of the PSF means that it is difficult in most instances to know the objective level of a particular PSF. In addition, uncertainty associated with interactions among the PSFs influences the HEP.

Contributory factors to uncertainty also include the appropriateness of the nominal HEP to the actual situation, the completeness of our understanding of the situation, and model uncertainty.

For simplicity, the effect of each PSF on the HEP for diagnosis or action-type task used in the SPAR-H method is assessed through multiplication. PSF influences are treated independently, as is the convention in HRA. For a discussion of the potential relationships among PSFs, see Section 2.5. As an enhancement to earlier versions of SPAR-H, the method now acknowledges that there is an advantage to being able to reduce the potential to double count shared effects among PSFs. As a result, an adjustment factor is provided with worksheets to allow the analyst to reduce the effects of this potential problem. Standard HRA also assumes that error can be appropriately modeled with a logarithmic function. Successful human performance may be modeled with a logarithmic function. This may not be the most appropriate function when these data are transformed into failure space.

The levels of PSFs are negatively skewed. More of the nonnominal ratings available for analyst selection are negative rather than positive. Emphasis is placed on nonnominal conditions that the regulator would expect to see. SPAR-H is expected to be used most often in situations where the cases under scrutiny are worse rather than better. Even so, use of positive PSF assignment can produce HEPs on the order of 1.0E-5, below which there should be only slight analyst confidence.

2.4.4 SPAR-H Method PSF Overview and Definitions

This section presents, in order corresponding to the SPAR-H worksheets, general definitions for the PSFs. As noted in other areas of this report, there is overlap among PSFs.

2.4.4.1 Available Time

Available time refers to the amount of time that an operator or a crew has to diagnose and act upon an abnormal event. A shortage of time can affect the operator's ability to think clearly and consider alternatives. It may also affect the operator's ability to perform. Multipliers differ somewhat, depending on whether the activity is a diagnosis activity or an action.

Diagnosis (At-power Conditions)

Inadequate time—P (failure) = 1.0. If the operator cannot diagnose the problem in the amount of time available, no matter what s/he does, then failure is certain.

Barely adequate time—2/3 the average time required to diagnose the problem is available.

Nominal time—on average, there is sufficient time to diagnose the problem.

Extra time—time available is between one to two times greater than the nominal time required, and is also greater than 30 minutes.

Expansive time—time available is greater than two times the nominal time required and is also greater than a minimum time of 30 minutes; there is an inordinate amount of time (a day or more) to diagnose the problem.

Insufficient information—if you do not have sufficient information to choose among the other alternatives, assign this PSF level.

The selection of 30 minutes for a minimum time for lowering the nominal diagnosis failure rate was made based on several factors. This time value comes from our reading of THERP diagnosis curves supplemented by the EDF MERMOS method. In addition, the methods differ in their approach to diagnosis and diagnosis-related actions. (MERMOS combines the two). This difference is sufficient to limit a truly empirical determination. Also, in situations where there is ample time but it is believed to be less than thirty minutes, analysts are expected to employ the "Obvious Diagnosis" category in the Complexity factor PSF. This was designed to correct for any over conservatisms in the diagnosis PSF levels.

The analyst is cautioned that "diagnosis time" reduces the time available for "actions" and vice versa. Since only one time is usually provided by the thermo hydraulic analysis, the analyst should keep track of the changing reduction in time.

Action (At-power Conditions)

Inadequate time—P (failure) = 1.0. If the operator cannot execute the appropriate action in the amount of time available, no matter what s/he does, then failure is certain.

Time available is equal to the time required—there is just enough time to execute the appropriate action.

Nominal time—there is some extra time above what is minimally required to execute the appropriate action.

Time available ≥ 5x time required—there is an extra amount of time to execute the appropriate action (i.e., the approximate ratio of 5:1).

Time available ≥ 50x time required—There is an expansive amount of time to execute the appropriate action (i.e., the approximate ratio of 50:1).

Insufficient information—if you do not have sufficient information to choose among the other alternatives, assign this PSF level.

The application of time available to LP/SD operation is discussed in other sections of this report.

2.4.4.2 Stress/Stressors

Stress (and level of arousal) have been broadly defined and used to describe negative as well as positive motivating forces of human performance. Stress as used in SPAR-H refers to the level of undesirable conditions and circumstances that impede the operator from easily completing a task. Stress can include mental stress, excessive workload, or physical stress (such as that imposed by difficult environmental factors). It includes aspects of narrowed attentional field or muscular tension, and can include general apprehension or nervousness associated with the importance of an event. Environmental factors often referred to as stressors, such as excessive heat, noise, poor ventilation, or radiation, can induce stress in a person and affect the operator's mental or physical performance. It is important to note that the effect of stress on performance is curvilinear—some small amount of stress can enhance performance, and should be considered nominal, while high and extreme levels of stress will negatively affect human performance (e.g., see Figure 2.4, p. 34).

Common measures of stress have included galvanic skin response (GSR), heart rate (HR), blood volume pulse (BVP), numerous self-report inventories, and the measurement of chemical markers. For example, lowered levels of s-IgA, an immune response marker present in saliva, have been linked to increased risk of ill health in individuals.[3] When applying SPAR-H, the analyst will not have the above physical measures available. Assignment of the specific stress level will therefore involve making an interpretation based on operations knowledge and human factors as to the expected level of stress for a particular scenario or context.

Extreme—a level of disruptive stress in which the performance of most people will deteriorate drastically. 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., multiple instruments and annunciators alarm unexpectedly and at the same time; loud, continuous noise impacts ability to focus attention on the task; the consequences of the task represent a threat to plant safety).

Nominal—the level of stress that is conducive to good performance.

Insufficient information—if you do not have sufficient information to choose among the other alternatives, assign this PSF level.

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[3] Hans Selye, a physician from Germany who spent much of his professional career investigating stress, helped to define what we know about the physiological and psychological phenomenon we refer to as stress. His theory includes the general adaptation syndrome (GAS), a nonspecific response of the body to demands made upon it. This response is associated with specific measurable physical activation of various endocrine-related systems. He defined three stages of GAS: (1) alarm reaction, similar to "fight or flight," (2) resistance, which is a struggle to overcome, hard work, and limited rest or sleep; and (3) exhaustion, which is characterized when body systems crash, fatigue ensues, errors become prominent, and there is increased irritability. During this stage, the body is vulnerable to illness (colds, flu, acne), because there is reduced immunoresponse.

2.4.4.3 Complexity

Complexity refers to how difficult the task is to perform in the given context. Complexity considers both the task and the environment in which it is to be performed. 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 or practice. Complexity can also refer to physical efforts required, such as physical actions that are difficult because of complicated patterns of movements.

Figure 2-3 illustrates typical contributing factors to complexity. Identification of these complexity factors may be found in Braarud (1998), EPRI TR-100259 (1992), Gertman and Blackman (1994), and NUREG-1624 (2000). The SPAR-H analyst may wish to refer to these factors when evaluating the complexity PSF. It is recognized that a single complexity factor can result in different levels of influence on human-system interaction. For example, mental calculations required of operators may be slight or, given aspects of the event, may prove to be overwhelming. The same is true for combinations of factors. Because of this, assignment of the specific complexity level associated with an HEP is left to the analyst to determine. At the current time, there is no algorithm for inferring levels of influence based on which combination of factors is selected.

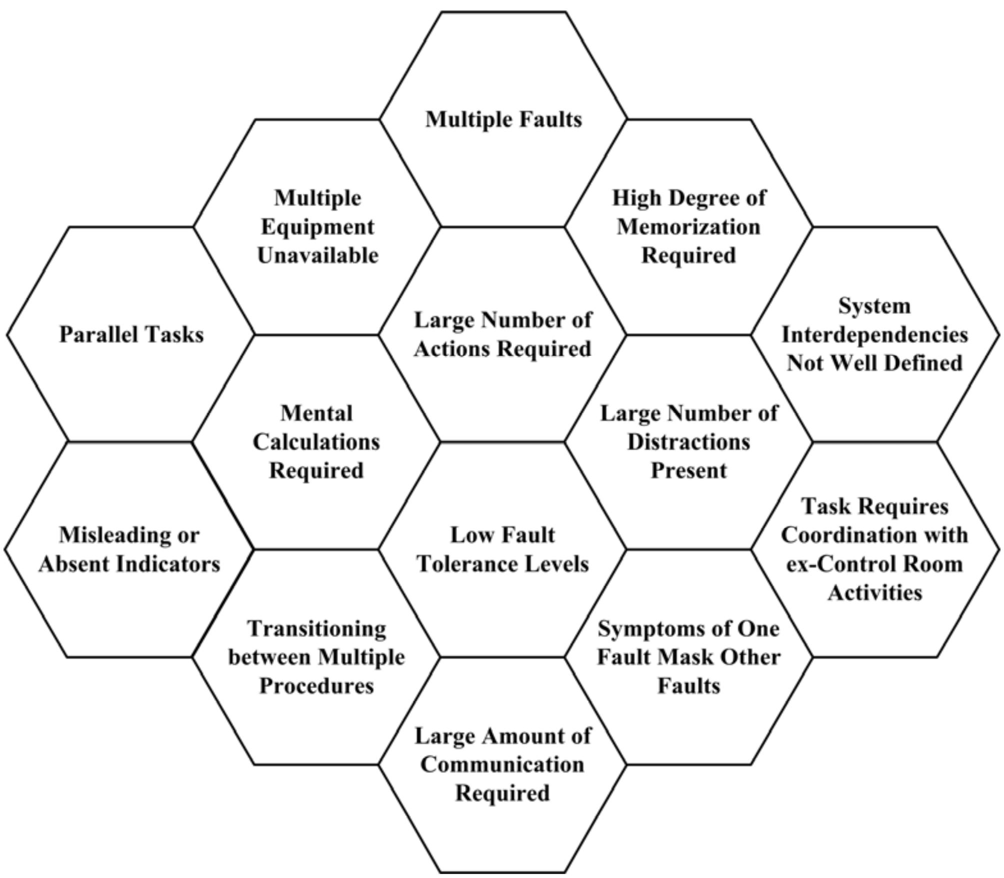

Figure 2-3. Factors contributing to task complexity.

For analysts who wish to differentiate between rule- and knowledge-based diagnosis, in most cases the former would present less complexity and would often be associated with a positive rating on the procedures PSF. Knowledge-based diagnosis and decision-making will often present the operator with greater complexity and often be associated with more negative ratings on procedures, including incomplete or misleading procedures or lack of procedural guidance.

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.

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 (i.e., unfamiliar maintenance task requiring high skill).

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 (i.e., evolution performed periodically with many steps).

Nominal—not difficult to perform. There is little ambiguity. Single or few variables are involved.

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 it. 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. For example, a radiation alarm in the secondary system, pressurized heaters, or a failure of coolant flow to the affected steam generator are compelling cues. They indicate a steam generator tube rupture (SGTR). Diagnosis is not complex at this point; it is obvious to trained operators.

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 choose among the other alternatives, assign this PSF level.

2.4.4.4 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, 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.

Low—less than 6 months 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 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.

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 choose among the other alternatives, assign this PSF level.

2.4.4.5 Procedures

This PSF refers to the existence and use of formal operating procedures for the tasks under consideration. Common problems seen in event investigations for procedures include situations where procedures give wrong or inadequate information regarding a particular control sequence. Another common problem is the ambiguity of 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, i.e., inadequate, then, the HRA analyst should assess the procedures and determine whether they should be assigned an "inadequate" or "poor" rating.

Diagnosis

Not available—the procedure needed for a particular task or tasks in the event is not 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.

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 choose among the other alternatives assign this PSF level.

Action

Not available—the procedure needed for a particular task or tasks in the event is not available.

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

Available, but poor—a procedure is available, but it contains wrong, inadequate, ambiguous, or other poor information. An example is a procedure that is so difficult to use, because of factors such as formatting, that it degrades performance.

Nominal—procedures are available and enhance performance.

Insufficient information—if you do not have sufficient information to choose among the other alternatives, assign this PSF level.

2.4.4.6 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 human machine interaction (HMI) are included in this category. The adequacy or inadequacy of computer software is also included in this PSF. Examples of poor ergonomics may be found in panel design layout, annunciator designs, and labeling.

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

Examples of poor annunciator designs have been found where only a single acknowledge circuit for all alarms is available, which increases the probability that an alarm may not be recognized before it is cleared. Another problem exists where annunciators have set points for alarms that are set too near to the affected parameter for an operator or crew to react and perform a mitigating action.

Examples of poor labeling include instances where labels are temporary, informal, or illegible. In addition, multiple names may be given to the same piece of equipment. Ergonomics of the plant are also called the human-machine interface (HMI) or the human engineering aspects. 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 LP/SD, certain information is assumed for the nominal ergonomics case. For BWRs this includes availability of RCS level instrumentation and RHR system instrumentation. For PWRs, this includes the availability of RHR system instrumentation, the availability of RCS temperature instrumentation, and the availability of RCS level instrumentation.

Missing/Misleading—the required instrumentation fails to support diagnosis or postdiagnosis behavior, or the instrumentation is inaccurate (i.e., misleading). Required information is not available from any source (e.g., instrumentation is so unreliable that operators ignore the instrument, even if it is registering correctly at the time).

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).

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 choose among the other alternatives, assign this PSF level.

2.4.4.7 Fitness for Duty

Fitness for duty refers to whether or not the individual performing the task is physically and mentally fit to perform the task at the time. Things that may affect fitness 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.

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 nonalert; 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.

Insufficient information—if you do not have sufficient information to choose among the other alternatives, assign this PSF level.

2.4.4.8 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 may 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. Measures could include amount of rework, risk worth of items in utility corrective action program backlog, enforcement actions, turnover, performance efficiencies, etc.

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 practices category, as are problems associated with a safety-conscious work environment. This includes retaliation by management against allegations as it pertains to the 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 practices PSF is assigned.

Additionally, any evidence obtained during the review of an operating event indicating inter-group conflict and decisiveness (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 it may 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 as required by regulation, is considered in SPAR-H as a work process variable. Because there are so many potential areas of concern within the work process category that can be assigned to a potential 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 process PSF level.

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).

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 choose among the other alternatives, assign this PSF level.

2.5 Application of Multiple PSFs

Reer (in OECD NEA 1998) and others have noted that the direct application of multiplicative models employing PSFs for the purpose of calculating human error probabilities is only approximately correct. There are a number of issues. These include using a scalar (i.e., the PSF value) to multiply a probability, the uncertainty associated with PSFs and the skills of analysts in making PSF assignments, and the possibility, given multiple negative PSFs, that the resulting conditional HEP is greater than 1. Solving issues related to the mathematical correctness of multiplying a scalar times a probability or accounting for the varying degrees of uncertainty associated with individual PSFs is beyond the scope of this document. Proper implementation of the odds ratio (accounting for the number of successes as well as failures) can make the determination of conditional HEPs less conservative and can help to reduce the propensity for negatively influenced situations to result in probabilities greater than 1.

We offer a simple modification of the nominal error probability that meets mathematical requirements. It is not formulated on the basis of underlying theory regarding the relative orthogonality or nonorthogonality of the eight PSFs used in SPAR-H.

The formula applicable to the adjustment of the nominal human error probability is:

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

where *NHEP* is the nominal HEP. *NHEP* equals 0.01 for diagnosis, and *NHEP* equals 0.001 for action.

Monte Carlo trials were conducted to gauge the adjustment factor's effect on SPAR-H results. Using MATHLAB, a million sample points were used to generate the distribution and uncertainty. For purposes of the analysis, we assumed an analyst with little or no training in SPAR-H beyond the worksheets, and this report as a reference. Additional assumptions appertained. For example, we assumed that the combination of "unfit for duty" and "inadequate time" appear with a probability of p = 3.0E-5, corresponding to 4 standard deviations above or below the mean for a normally distributed variable. We assumed weights present for making the ratings to be normally distributed; however, less is known about the training and experience PSF. Therefore, probabilities from a uniform random probability distribution were generated accordingly. Three observations of experience were treated as equally probable—low, normal, and high. Each PSF was treated as a discrete variable, and a value under the area of the normal distribution was assigned for each level of the PSF. The large number of samples used in the simulation allows for assuming normalcy and central limit theorem applicability (i.e., as sample size increases, the sum approximates a normal distribution, and their product approximates a log normal distribution).

Although the constraints discussed above were operative, exercise of the simulation employing the adjustment factor resulted in 12% of the HEP estimates yielding a value of 1. This is in comparison to similar analyses without the adjustment factor, employing the same sampling and distribution assumptions where the HEPs with a value of 1 were 27% of the sample.

For purposes of the simulation, the rule for applying the adjustment factor was the same as that used on the worksheets. The adjustment factor was used when three or more PSFs were assigned negative ratings. Thus, in situations where a strong negative context is present, we feel that it is possible to obtain sufficiently high HEPs.

The type of HEP selected for this analysis was a joint HEP, with both diagnosis and action considered. In SPAR-H, this type of failure event typically produces a higher HEP than diagnosis or action alone and was assumed to be a good case for examining the potential of the adjustment factor to reduce the more extreme HEP values. Further analysis could be directed at review of the effect of the adjustment factor upon individual diagnosis and action HEPs. In addition, research could be directed to evaluate the effect of changes to the dynamic ranges of PSFs upon HEPs. For example, in cases where the PSF multiplier is 50, Monte Carlo simulation could be used to determine the effect in the underlying HEP distribution if that range were reduced from 50 to 20 or 30 times the nominal HEP.

2.5.1 Calculating the Composite PSF

The composite PSF is calculated as the product of the analysts ratings of all PSFs contained on the SPAR-H worksheet. The ratings are multiplied by one another, regardless of whether the PSF influence is positive or negative. The adjustment factor covers a large variety of combinations where the combined PSF influence would, if no adjustments were applied, result in a probability greater than one.

2.5.1.1 Example 1: Diagnosis for Sequence at Plant A

A diagnosis activity is required. Review of the operating event by the Augmented Inspection Team (AIT) revealed the following PSF parameters to have influenced the crew's diagnosis of loss of inventory: procedures were misleading; displays were not updated in accordance with requirements (ergonomics and human-machine interface); and the event was complex due to the existence of multiple simultaneous faults in other parts of the plant. The report mentioned no unusual or negative PSF influences contributing to the event beyond those listed above.

The assignment of the PSF levels and associated multipliers is as follows (Appendices A and B may be consulted for a list of other PSF levels):

PSF	Status	Factor
Procedures	misleading	(10)
Ergonomics	poor	(20)
Complexity	moderately complex	(2)

PSF composite score = (10·20·2) = 400

Ordinarily, application of the multiplicative approach without application of an adjustment factor would have yielded a probability of 4.0. In that case, the analyst would have used HEP = 1.0, and have been overly conservative in that assignment. The same formula may be applied to the calculation of the HEP for the SPAR-H Action worksheet.

The adjustment factor for Example 1 is as follows:

$$HEP = \frac{.01 \cdot 400}{.01 \cdot (400-1)+1} = 0.81 \ .$$

The adjustment factor is also applicable in situations determined where the positive influence of PSFs is present.

2.5.1.2 Example 2: Action for Sequence at Plant A

Operators are required to take an action to return a pump to service. The AIT reports that work processes at the plant regarding the operation and maintenance of this equipment are strongly positive, the training and experience of the crew is high (they have received offsite training and all have 10-15 years operations experience), and there is ample time (longer than 30 minutes and more than 2 times the time required). For this scenario, no other HEPs were mentioned in the report and insufficient information was noted on the SPAR-H worksheet. The HEP with the adjustment factor applied would be calculated in the following manner:

PSF	**Status**	**Factor**
Work processes	Positive	(0.8)
Training	Positive	(0.8)
Time available	Extra time	(0.1)

PSF composite score = (0.8·0.8·0.1) = 0.064

Ordinarily, application of the multiplicative approach without application of an adjustment factor would have yielded a human error probability estimate of HEP = 6.4E-5.

The conditional HEP representing the composite PSF influence is determined by:

$$HEP = \frac{0.001 \cdot 0.064}{0.001 \cdot (0.064-1)+1} = \frac{0.000064}{0.999064}$$

= 6.41E-5.

In the positive case, the influence of the adjustment factor is less than in the first example, where there is a pronounced effect of negative PSFs upon the nominal failure rate. Also, the SPAR-H PSFs are negatively skewed, having a larger relative range of influence for negative situational influences. The most influential positive PSF is found in situations where there is expansive time available for crew response and opportunity for them to consult with others, such as the tech support center, the licensing engineer, or the crew for the next shift. In general, SPAR-H is expected to be applied by NRC staff when performing event analyses where the majority of situations reviewed are expected to be negative rather than positive.

2.6 Dependency

A dependency method was developed in 1994 that yielded a dependency rating from zero to complete dependency. These levels were then matched to the nomenclature in THERP.

In 2003, the SPAR-H method was again updated, this time to allow for analysts to acknowledge additional aspects of context when considering dependency.

The approach is meant to highlight those actions or diagnoses that should be further reviewed and for which higher failure rates can be assumed.

This does not represent an exhaustive characterization of dependency but does bring a degree of standardization and representation to the HRA process. Table 2-4 presents the dependency table that analysts use to assign a dependency level. The leftmost column presents the criteria developed by the INL in 1999. The center column, the five levels of dependency, is from NUREG/CR-1278. The right-hand column was developed for the current SPAR-H revision and represents other descriptions developed for application with the SPAR-H method that may aid the analyst in mapping tasks, PSFs, and other aspects of context to the appropriate dependency level. A brief discussion follows. Note that discretion is 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.

We believe that dependency of one task upon another arises from the knowledge or lack of knowledge of the performer of the second task with respect to the occurrence and/or effect of the previous task. This dimension of knowledge cuts across the model of human performance presented in Figure 2-1. Mental models are updated to coincide with experience and, therefore, are impacted by the same summary level factors or PSFs that are shown in Table 2-3 (available time, complexity, stress and stressors, work processes, experience and training; procedures, ergonomics and human-machine interface, and fitness for duty). For example, cues such as alarms, indicators, chart recorders, CRT-based alarm lists, are what the operators attempt to attach to their model of the situation. The more accurate the cues provided during training and subsequently stored by the operator, the greater the tendency that he or she will take the correct action. Prior actions and errors can act as current cues and establish expectancies leading to propensities to look, or not to look, for specific pieces of information. In other words, previous actions or recently experienced events create a mindset that guides decision making.

At the top level, if the operator has no knowledge of a prior task, then that task has no effect. Obviously, this is meant from a cognitive perspective. For example, if a pump is damaged out in the field, this operation can make pump re-start impossible. If the operator has knowledge of the prior task, then we must consider what that knowledge could affect. For example, the relationship between dependency and stress if the prior task has failed will produce a higher level of stress. This may influence subsequent task performance. For available time, the important factor is whether excessive time required to take one action leaves less time for the next, thereby influencing the failure rate.

A number of factors can operate to make a series of errors dependent. Some of these include: whether the crew performing the current task is the same or different than for the prior task; whether the current task is being performed in the same or different system than the prior task; whether the

Table 2-4. SPAR-H Dependency Rating System.

Crew, Time, Location and Cue Assignments (SPAR-H 1999 Revision)	SPAR Dependency Level (NUREG/CR-1278 1983)	Additional Dependency Considerations and Basis for Interpretation (SPAR-H 2004 Revision)
Same crew, close in time, same location, with or without additional cues	Complete	Lack of feedback, misleading feedback or masking of symptoms *virtually ensures* that preceding failure will cause failure on this task as well. And/or Situation mimics an often-experienced sequence, and sequence triggers a well-rehearsed, well-practiced response. A lapse, slip, or mistake is virtually ensured. Or Time demand, workload, or task complexity is such that failure on a preceding task ensures a lapse, slip, or mistake on this task.
Same crew, close in time, different location, with or without additional cues	High	Lack of feedback, misleading feedback, or masking of symptoms makes it highly likely that preceding failure will cause failure on this task as well. And/or Situations mimic an often-experienced sequence; sequence triggers a well-rehearsed, well-practiced response. A lapse, slip, or mistake is highly likely to result. Time demand, workload, or task complexity is such that failure on a preceding task makes a lapse, slip, or mistake on this task highly likely.
Same crew not close in time, same location, no additional cues	High	Lack of feedback, misleading feedback or masking of symptoms makes it highly likely that preceding failure will cause failure on this task as well. And/or Situations mimic an often-experienced sequence; sequence triggers a well-rehearsed, well-practiced response. A lapse, slip, or mistake is highly likely to result. Time demand, workload, or task complexity is such that failure on a preceding task makes a lapse, slip, or mistake on this task highly likely.
Same crew, not close in time, same location, additional cues	Moderate	Lack of feedback, misleading feedback, or masking of symptoms makes it moderately likely that preceding failure will cause failure on this task as well. And/or Situations mimic an often-experienced sequence; sequence triggers a well-rehearsed, well-practiced response. A lapse, slip, or mistake is moderately likely to result. Time demand, workload, or task complexity is such that failure on a preceding task makes a lapse, slip, or mistake on this task moderately likely
Same crew, not close in time, different location, no additional cues	Moderate	Same as above, except no cues.
Same crew, not close in time, different location, additional cues	Low	Lack of feedback, misleading feedback, or masking of symptoms makes it somewhat likely that preceding failure will cause failure on this task as well. And/or Situations mimic an often-experienced sequence; sequence triggers a well-rehearsed, well-practiced response. A lapse, slip, or mistake is somewhat likely to result. Time demand, workload, or task complexity is such that failure on a preceding task makes a lapse, slip, or mistake on this task somewhat likely
Different crew, close in time, same location, with or without additional cues	Moderate	Likely that preceding failure will cause failure on this task as well. And/or Situations mimic an often-experienced sequence; sequence triggers a well-rehearsed, well-practiced response. A lapse, slip, or mistake is moderately likely to result. Time demand, workload, or task complexity is such that failure on a preceding task makes a lapse, slip, or mistake on this task moderately likely
Different crew, not close in time, same location, no additional cues	Low	Same as above

current task is being performed in a different location than the prior task; whether or not the current task is being performed close in time to the prior task; and whether or not there are additional cues available for the performer of the current task that may serve to influence reaction time, failure rates, and recovery.

We considered the following variables: crew (same or different), time, location, and cues to construct a dependency matrix. These four parameters were combined into 16 dependency rules, yielding dependency ratings from low to complete dependence. A seventeenth dependency rule equal to zero dependency is also included in Part IV of the SPAR-H worksheets. Earlier versions of the SPAR-H worksheets featured a compact version of the dependency matrix. The full 16-level dependency matrix features considerable redundancy, e.g., events by different crews at different times will always have low dependency, regardless of location or cues. While earlier versions of SPAR-H merged redundant pathways into eight dependency rules, the current revision of SPAR-H incorporates the full matrix of 16 combinations plus zero dependency. Inclusion of the full dependency matrix affords the SPAR–H analyst greater traceability in his or her decisions about dependency relationships than was previously possible.

The dependency levels match the nomenclature used in THERP. Modification factors used in the SPAR-H method were taken from the THERP Tables. The approach was designed to be practical and at an appropriate level of detail for use in a screening analysis.

The right-hand column of Table 2-4 reflects combinations of factors derived from HRA evaluations of operating events and the application of HRA methods, such as ATHEANA (NUREG-1624 2000), that we judged to relate to different levels of dependency in THERP and the SPAR-H method.

2.7 Uncertainty Analysis Suggestions For Using SPAR-H

2.7.1 Overview

The SPAR-H method produces a simple best-estimate HEP for use in plant risk models. The application of PSF multipliers in the SPAR-H method follows a “threshold approach,” wherein discrete multipliers are used that are associated with various PSF levels. Since these are thresholds, the multipliers do not convey information regarding the uncertainty associated with the multiplier. For example, a multiplier of 10 from the available time PSF does not represent a range of multipliers (e.g., from 8 to 12). Instead, the multiplier represents a shift in the nominal HEP. Subsequent research efforts may wish to address the uncertainty associated with the assignment of thresholds.

The eight PSFs undoubtedly contain some overlap and are thus nonorthogonal. However, the SPAR-H method treats these influencing factors independently. Historically, in quantifying HEPs, HRA practitioners have treated these influencing factors as independent. In reality, dependence is unknown when simultaneously considering such a large group of factors (PSFs). It is unknown how this interrelationship affects the underlying probability distribution. However, a complex relationship is currently presumed. The relative relationship (i.e., correlation) of these factors to one another is discussed separately in this section of the report.

In defining multipliers associated with mean threshold times, a potentially large spectrum of diagnosis types is reflected. The average time for diagnosis can, of course, vary as a function of plant conditions, PSFs, and other contributions to context. It is those factors that are used by the analysis team in determining their best estimate of the required diagnosis time, and the time available to the crew (usually based upon thermal hydraulic calculations). A number of assumptions underlying human performance in conjunction with plant performance are incorporated in the SPAR-H method and are presented below.

2.7.1.1 Assumptions

- There is a nominal rate associated with diagnosis and action-type tasks. This is consistent with traditional HRA approaches.
- The nominal rate can be influenced by a number of factors determined by review of the psychological literature. These factors are the PSFs. Eight such factors are used in the SPAR-H method.
- For noninitiators the probability associated with the HEP ranges from 0 to 1. The SPAR-H method has not been designed to work with initiators; rather, analysts should identify frequencies to be used for those applications.
- The SPAR-H method assumes that the best (i.e., the most informative) piece of information available regarding the human error probability is the mean. When multiplying the base failure by the PSF (multiple PSFs), the resultant value is a mean value with its own range of uncertainty.

2.7.1.2 Caveats

Some HRA approaches, such as THERP and ASEP, made use of lognormal error factors, which often produced upper bounds for HEPs that were greater than one. Practitioners were aware of this illogical conclusion and accepted it because of base assumptions regarding lognormal distributions of human performance and inabilities to move easily away from these normal and lognormal distributions as a basis for these human performance models.

The SPAR-H method does not use error factors, nor does it assume the use of a lognormal probability distribution. The SPAR-H method ultimately employs a beta distribution, which can mimic normal and lognormal distributions (in addition to other types of distributions).

A so-called "constrained non-informative prior" (CNI) distribution (Atwood 1996) is used, due to several factors:

- It takes on the form of a beta distribution for probability-type events.
- It uses a noninformative prior distribution as a starting point for the Bayesian distribution transformation.
- It preserves the overall mean value (after multiplication of the PSFs on the nominal HEP), which is the focus of the worksheet.
- It does not require extra uncertainty parameter information, such as a standard deviation or upper and lower bounds.
- It can produce small values at the lower end of the distribution (e.g., <1E-6), but the upper end of the distribution more properly represents the expected error probability. Note that it is the upper end of the distribution that dominates the overall uncertainty results.

An artifact of the SPAR-H worksheet is the situation where, if the majority of PSFs are positive, the mean values can be less than 1.0E-5. In this situation, a cutoff value of 1.0E-5 is suggested. For diagnosis tasks, the base rate (mean) is approximated as 1.0E-2. This estimate is based on our review of the literature of HRA methods. For action tasks, the mean nominal value is assumed to be 1.0E-3.

HRA and human factors have not been able to demonstrate sensitivity between situations where failure rates may be in the 1E-5 versus the 1E-6 range. Therefore, 1E-5 is a justifiable lower cut-off range.

Recent versions of the ASME Standard on PRA (2002) have suggested that analysts consider the maximum entropy formulation when calculating uncertainty. This approach is similar to that used by the SPAR-H method, wherein we use the CNI distribution (which is a special type of maximum entropy distribution). Therefore, the following is presented as a proposal as to how uncertainty may be calculated using our approach. As a matter of convenience, we assume that analysts will have access to SAPHIRE (Smith et al. 2000) software when performing this calculation, but availability of this specific software is not necessary.

2.7.2 Human Performance Distributions

Basic research in human performance has identified a number of models specific to human performance. Associated with these models are distributions of human performance and distributions of human error. The most fundamental of these models are presented below.

2.7.2.1 Fitts' Law

Research by Fitts and Seeger (1953) is seminal work in the psychological literature examining choice reaction time and is related to the SPAR-H action tasks. Fitts found that movement time (*MT*) was equal to the log of two times the distance from the starting point to the target, divided by the size of the target. The distance over size function is regarded as the index of difficulty (*I*) of that movement. The distribution was determined over hundreds of measures of hundreds of subjects. The equation follows:

$$MT = \log_2\left(2\frac{D}{W}\right)$$

where *D* is the distance from the starting point of the motion to the center of the target, and *W* is the width of the target.

Fitts' Law demonstrates that the time required to complete a task is an inverse function of the precision or accuracy required. The greater accuracy or precision required in a task, the longer the amount of time that is required for that task. Similarly, short time intervals decrease the level of accuracy that can be expected. In other words, there is a speed-accuracy tradeoff. While Fitts' Law is not currently a prescriptive formula for human error, it provides insights into time and accuracy considerations when modeling HEPs.

2.7.2.2 Hicks' Law

Hicks' (1952) Law regarding decision times represents research from the 1940s and 1950s refers to subjects' performance when presented with simple choice-type tasks, and is related to the SPAR-H method diagnosis task type. The decision times (*T*) associated with selecting a choice increase according to the number of binary choices:

$$T = I_C H$$

where $I_{c\,=}$ 150[0-157]msec/bit and *H* is the amount of information required to make the decisions and is measured in bits. This reflects the fact that people do not linearly consider each alternative in the order presented when making a simple decision. Instead, they use a hierarchical process that classifies the alternatives into the most likely ones first. For nearly equally probable alternatives:

$$H = {}_{\log 2}(n+1) \ .$$

When the choices carry different amounts of information, and/or have a different probability of occurrence, the relationship among choices and reaction time is still logarithmic, and can be modeled as:

$$H_i = \log_2 \frac{1}{p_i} \ .$$

This formula allows *H* to increase as the probability of the event *i* decreases. Since we use time as a PSF to influence HEPs, and taking longer time to diagnose either due to multiple choices or to different amounts of information available increases the time required to diagnose, this work may have relevance for the SPAR-H method application.

2.7.2.3 Stevens' Power Law

Stevens' (1951) Power Law may have relevance for the SPAR-H method PSF for training and experience. A variation of this law simply states that the logarithm of the reaction time for a particular task decreases linearly with the logarithm of the number of practice trials taken. Qualitatively, the law simply says only that practice improves performance. The law has proven applicability to a wide variety of different human behaviors—immediate-response tasks, motor-perceptual tasks, recall tests, text editing, and more high-level, deliberate tasks such as game playing. Therefore, this law is applicable to the SPAR-H method diagnosis and action-type tasks.

Steven's Power Law suggests that if actions are practiced over a period of time, performance tends to improve. The result of his work is a power function for performance. This could be modeled as the inverse, which would be a logarithmic function. The function is:

$$RT = aN^{-b}$$

where $a = RT$ on trial 1, b can be approximated by 0.4, and N is the number of trails.

2.7.2.4 Other Laws

Additional laws for performance are associated with these fundamental laws. For example Meyer's Law (Meyer et al. 1988) refers to rapid motions, which may occur in human-computer interaction. This corresponds to one aspect of the SPAR-H method PSF ergonomics and human-machine interface:

$$T = A + B\sqrt{\frac{D}{W}}$$

where T is the time to move to a target, D is the distance to the target, W is the width of the target, A is approximately -13 msec, and B is approximately 108 msec.

Meyer's Law is a refinement of Fitts' Law for predicting the time it takes for rapid aimed movements, such as hitting a button on the screen by moving a mouse to it. (A and B are constants that may vary with the input device.) This model suggests that this aspect of human performance can be modeled with a logarithmic function.

Meyer's Law is derived from a stochastic optimized-submovement model. This model says that movements consist of a primary submovement and a possible corrective secondary submovement toward a target. Meyer's Law can be used to make predictions of how much time it will take for a user to accomplish a task involving selection of targets on the screen (such as icons, menus, or hypertext links).

Another fundamental law that has driven significant research in human performance is Yerkes-Dodson's Law (1908). Yerkes-Dodson's Law states that performance is an inverted U-shaped function of attention (see Figure 2-4). In other words, performance is a quadratic function of arousal.

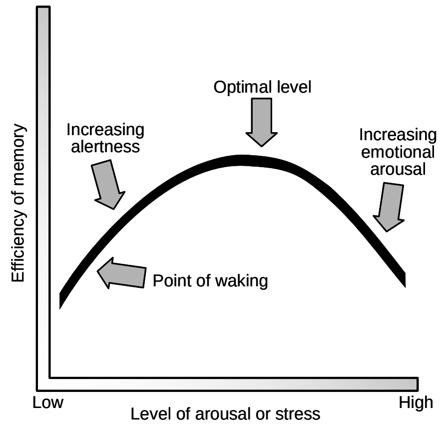

Figure 2-4. Arousal effect on memory.

Arousal level can be thought of as the available capacity for work. A certain amount of arousal is a motivator toward learning. Too much or too little change can prevent learning or memory from forming. A mid-level of arousal provides the optimal level for the formation and retrieval of memories. There are optimal levels of arousal for each task to be learned. The optimal level of arousal is lower for difficult or intellectual (cognitive) tasks (the operators need to concentrate on the material) but higher for tasks requiring endurance and persistence (the operators need more motivation).

This arousal and performance relationship has significance for the SPAR-H method PSF fitness for duty, since that PSF covers circadian upset and fatigue effects. It also relates to the PSFs for complexity and stress and stressors. As a quadratic function, it is more properly modeled as a beta than a logarithmic distribution. For a discussion of the appropriateness of using beta in uncertainty analysis, see Section 2.6.3

A final example of the available models of human performance that do not necessarily require the assumption of a normal distribution of error is the feature model presented by Nairne (1990). In fact, a variety of distributions were observed in our review of the performance literature. The transformations of these various distributions to a beta distribution is legitimate and preferred over ad hoc, log normally based techniques.

The feature model may have relevance for diagnosis or action tasks and is performance-based. Representations of items in memory are vectors that code the *features* of an item using a binary system, allowing features to assume the values of +1 or –1. Features are pattern elements, which can be semantic or perceptual and may be coded according to a specific sensory modality, or modality independent coding information that can be conveyed equally by one or more modalities. Thus, a series of alarms or other indication can come to signify a particular plant event such as a loss-of-coolant inventory, etc. The goodness of the fit between the alarms and signals received by the crew to what they have been trained to expect determines whether or not a correct diagnosis or correct action will be undertaken.

Cues can degrade if they are not stored properly or if something else is experienced that overwrites the presence of that cue. As Beaman (2000, p. 38) notes, memory "consists of finding the best match to a degraded cue amongst a set of undegraded feature vectors that reside in secondary memory (SM)." In other words, based on the cues present at the time of recall, the operator attempts to rebuild the original item from the available cues to reach the appropriate diagnosis. This retrieval and reconstruction process can be modeled as follows: "The [difference] between the degraded item and its undegraded secondary memory representation is calculated by summing the number of mismatched features, *M*, and dividing by the total number of compared features, *N*, as described [here]:

$$d_{ij} = a\sum \frac{b_k M_k}{N} \ .$$

"The value M_k is the number of times feature position x_{jk} does not equal feature position x_{jk}. The parameter *a* is a scaling parameter that is assumed to correspond to the overall level of attention, and b_k is used to weight particular comparisons if the task makes them more important than other comparisons. Distance, *d*, is then used to calculate the similarity between the degraded vector and the undegraded secondary memory representation according to:

$$s(i,j) = c^{-d_{ij}} \ .$$

"The probability that a particular secondary memory trace, SM_j, will be sampled as a potential recall response for a particular degraded memory vector, PM_i, is then given by

$$P_s(SM_j \mid PM_i) = \frac{w_{ij}s(i,j)}{\sum_{k=1}^{N} w_{ik}s(i,k)}$$

where w_{ij} and w_{ik} are possible response bias weights." In a practical sense, the analyst would review an event, determine whether cues for which operators were trained on for that event type are present, determine whether new/extraneous cues yielding alternate states are present, and then determine the match between expectancies and the true state.

In this model, the degree of fit with experience and expectancy, rather than time available, is key. This model explains and is congruent with most memory phenomena. As shown by the similarity function above, this model of cognitive performance is based on the natural log, and therefore can be modeled within the beta distribution.

2.7.3 Work Shift Effects

The relationship of human performance to work shift is well documented. This factor can show up in two SPAR-H method PSFs—fitness for duty as it relates to circadian and fatigue effects and ergonomics for the extent to which it reflects error tolerant design, based on knowledge of workshift effects. Dorel (1996) reviewed the importance of the temporal dimension in influencing human performance. Even within correct performance, there is a high amplitude effect; tasks are performed differently within tolerances, depending on the time of day. Work processes may be carried out differently, and supervision may also be susceptible to these influences.

Even for the layperson, reduced concentration is acknowledged for different times of the day. Dorel (1996) reviewed the nuclear power plant archives in France for the period 1981 through 1989, assembling data for dates and times during which human failures occurred. Data covered periods of both at power and LP/SD, and were collapsed across task type, location, and the number and type of operators involved. Shift rotation factors were found to be important; most failures within morning or afternoon shift occur during the first part of the shift, shortly after shift changeover and next by failure at the end of the shift. Failures across the night shift were distributed evenly. However, relatively greater errors occurred during the night shift than during the afternoon or morning shifts.

Some 110 failures across three facilities were documented. There was no significant correlation between facility type and the temporal variable under investigation; data were collapsed across facilities. Frequencies for failure were greatest for the night shift, followed by the day shift, and then by the afternoon shift. The difference between the morning and the afternoon shifts was significant ($p = 0.035$). The approximate frequencies were 41.25 (night), 33.75 (morning), and 18.75 (afternoon), respectively. The authors report that rest times and slow versus quick alternation for shift change can also influence failure. The relative frequency of these effects follows a linear progression that can be represented in a beta distribution.

2.7.4 Human Performance and Complexity

Historically, complexity was part of information theory espoused by Shannon (1949) and others. Over time, complexity has taken on many different meanings. Complexity, as used in the SPAR-H method, considers multiple factors, such as difficulty, ambiguity, occurrence of multiple faulted conditions, familiarity, and availability of job performance aids to reduce and cope with the complexity, etc. The human performance literature has defined complexity in various ways. One of the simpler approaches in the early 1960s by Rasch was to define complexity as a function of ability in the presence of difficulty. This was assessed on an individual basis. This research was first performed to determine the relative difficulty of test items. Different raters were to rate the items. Normalization across rater ability was determined as part of the approach. Florin cites Rasch's model in the following manner:

$$L_{ni} = \frac{B_n}{D_i}$$

where B_n is the level of ability of the n^{th} person, and D_i is the difficulty of the i^{th} test item.

The greater the ability of the test taker, the higher the Rasch performance measure. Similarly, the greater the item difficulty, the lower the score or rating. This can be criticized, because it implies that a $f(B_n) = -f(D_i)$. Ability is the sole determinant of difficulty. This may not always be the case for real-world tasks. For example, simple tasks can be perceived to be difficult by able persons when there is insufficient time available. Also, in the face of poor ergonomics, capable crew members maintain their ability even though the task has been made more difficult, whereas less capable crews do not maintain their ability as well. In either case, performance is expected to degrade. This is the importance of PSFs.
Various refinements and applications of the Rasch model have received attention. Linacre and Wright (2002) supplement the original Rasch approach by suggesting an objective method to determine difficulty of a test. Frequencies are calculated for the following four conditions:

		Person N	
		Right	Wrong
Person M	Right	*a*	*c*
	Wrong	*b*	*d*

Because the cases where person M or person N answers the same is uninformative, the only informative contrasts come from cells *b* and *c*. Therefore, the probability of occurrence in cell *b* can be expressed as:

$$\frac{p_{ni} \cdot (1 - p_{ni})}{(1 - p_{ni}) \cdot p_{ni}}$$

where *i* refers to the test item, and p_{ni} indicates the probability of person *N* on item *i*. Thus, $1\text{-}p_{ni}$ is the probability of failure of person *N* on item *i*. Cell *c* is similar, with the numerator and the denominator reversed. Through mathematical transformation, Wright and Linacre demonstrate that the above equation could be reduced to:

$$\frac{p_{ni}}{(1-p_{ni})}\ .$$

This can be further transformed into an equal interval linear scale with a logarithmic function with the following form:

$$\log \frac{p_{ni}}{(1-p_{ni})} = B_n - D_i$$

or

$$p_{ni} = \frac{e^{(B_n - D_i)}}{1 + e^{(B_n - D_i)}}\ .$$

Thus, the item or test (or task difficulty) only depends on the attributes of item *i*, and B_n is the measure, depending only on the attributes of person *n*, which can be called his or her ability. Review of these two approaches suggests that: (a) there may be merit in accounting for complexity from both a subjective, as well as an objective measurement perspective; (b) difficulty (complexity) may be more than the inverse of ability; and (c) research in complexity should consider the potential influence of performance-shaping factors. Recent research addresses aspects of these three points.

Research by Braarud (2002) reports three simulator experiments in process control that establish a relationship between task complexity and the performance of control room crews. In a comparison of measures employed, it was determined that the mental workload measures covered in the NASA task load index (TLX) workload measures inventory were accounted for by the concept of complexity. He proposes that task complexity is characterized as task characteristics that make it difficult for an operator or crew to reach the desired end state. Inclusion of difficulty as part of the definition of complexity relates to Rasch's conceptualization of complexity. In all instances, however, the determination of complexity must acknowledge ability that mediates aspects of difficulty. To this end, subjective measures of complexity must accompany objective complexity measures.

This approach is embraced as part of the Halden Reactor Project work. Complexity data collected were collateral to the three studies: review of the impact of staffing level on performance (Hallbert et al. 2000); evaluation of the impact of alarm system design on crew performance (O'Hara et al. 2000) and the influence of automation malfunctions on crew performance (O'Hara et al. 2000). A 39-item inventory was designed and administered. The researchers sought to determine whether a refined set of self-report items could be determined.

Three performance measures were identified: (1) operator activity against an ideal solution path; (2) rated performance across solution path, control of plant, communication, and confidence as measured by trained observers; and (3) system performance, as measured by general and scenario plant-specific parameter sets. Parameter development was performed by experts who ran simulator trials to determine the ideal parameter set. Experimental controls were established to minimize differences among subjects participating in the study and to reduce any differences obtained as a function of differences among the experimental scenarios. Subjective ratings of complexity were significantly related to operator performance (i.e., solution path, rated performance, and system performance). For Study 3 (automation malfunction), significant correlations were determined for all three measures of performance, while for Study 2 (alarm system design characteristics), they were only present for system performance. Highest correlations were observed for subjective complexity and systems performance. Overall, there was a moderate tendency for high complexity to be associated with reduced performance.

Once the distribution of the behavior of human activity (e.g., diagnosis, action) is known, this information may be used in the context of Bayesian analysis to determine HEPs and their associated uncertainty distributions. An analogy from the hardware-portion of the PRA relates to time-based component failures. For a component family that has a constant rate of failure, the time between failures is exponentially distributed. However, this information on the outcome (time to failure) is combined with the assumption of a Poisson process to determine a failure probability and associated distribution. For the case of a Poisson likelihood, a gamma distribution provides a conjugate distribution. Thus, the resulting distribution on the component failure rate would be gamma distributed.

2.7.5 The Categorization and Orthogonality of PSFs

The majority of well-controlled studies involving human performance research are conducted in such a manner as to determine the relationship of important variables two at a time. Examples of this type of research are presented above and are relevant to the use of PSFs in HRA.

There is limited research in the human performance literature defining the simultaneous interrelationships among groups of factors that are agreed upon to influence performance. Factor analysis statistical techniques have been employed in the behavioral sciences, but mostly to develop inventories that can be used to assess psychosocial (i.e., clinically relevant) traits in individuals as an adjunct to therapy or to aid in the job selection process. The Minnesota Multiphasic Personality Inventory (MMPI; Hathaway and McKinley 1942) is an example of an inventory that is used to support clinical intervention and therapy as well as the job selection processes at nuclear installations.

Research has also been performed to find appropriate objective and subjective measures of PSFs, such as workload, complexity, stress and stressors, training, fatigue, and general personality and social variables (Proctor and Van Zandt 1994; Wickens and Hollands 1999). At least one recent study, Hallbert et al. (2000), in reviewing staffing levels for advanced and current control rooms at nuclear power plants, was able to estimate some degree of overlap among these measures.

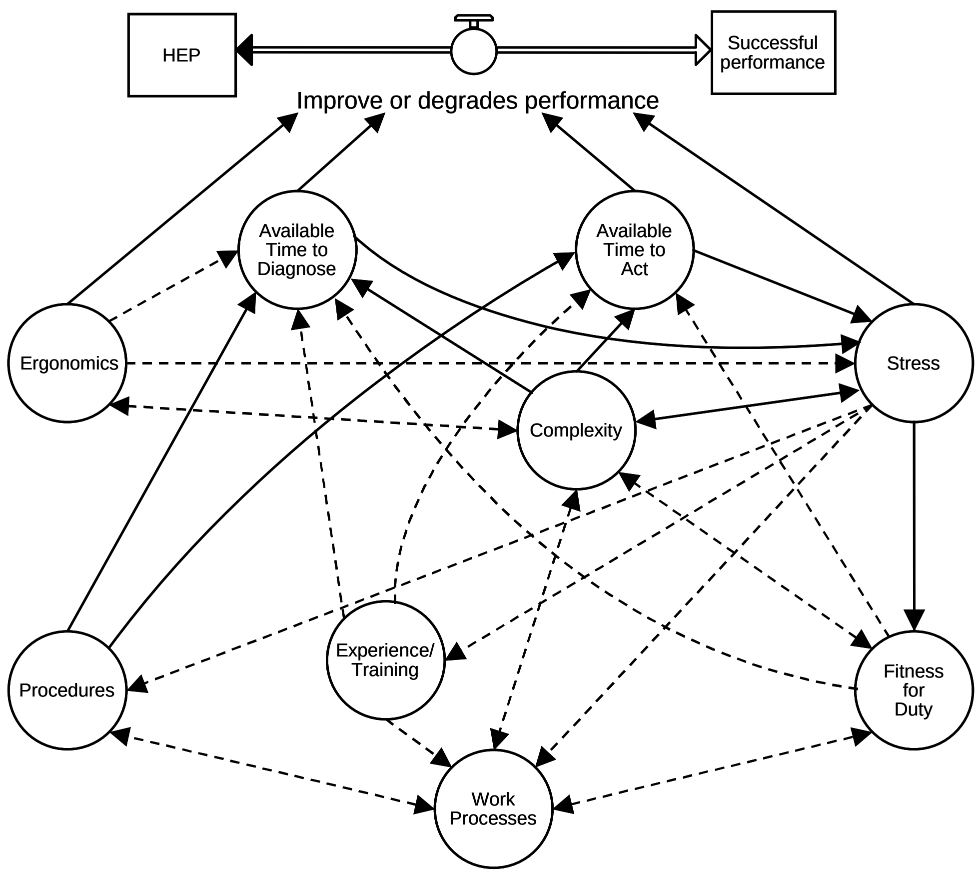

Figure 2-5. Path diagram showing relationships among PSFs (solid lines denote *high* degree of relationship, dashed lines denote *medium* degree of relationship); see Table G-1.

In an effort to guide analyst thinking regarding the issue of dependence and to help prevent the analyst from double-counting influences when assigning PSF threshold values in HEP quantification, the INL produced a table that assigns a qualitative ranking (low, medium, or high) of the degree of correlation among the eight PSFs. The 64-cell table, presented in Appendix G as Table G-1, is only to be used as a guide.

Dependence among these factors could make the SPAR-H method-calculated HEPs either too conservative or too optimistic. For example, when reviewing the deleterious effects of PSFs upon performance, correlated factors will make the resulting HEP more conservative than is the case. Conversely, when reviewing HEPs where strongly positive PSFs are present, it is possible that the final HEP will be overly reduced.
Figure 2-5 presents a path diagram of the relationship among PSFs that was determined based on Table G-1. The figure presents medium and high relationships and direct versus indirect influences upon HEPs.

From Table G-1 and Figure 2-5, a few preliminary conclusions can be drawn. First, the relationship may be one-way, that is, PSF_i may influence PSF_j strongly, whereas PSF_j may have little or no effect on PSF_i. For example, available time has a strong influence on stress; however, stress has a low effect on available time, which is often the product of system conditions and equipment unavailability.

Second, some PSFs share an inverse relationship. That is, as PSF_i increases, PSF_j decreases. For example, as job experience increases, workers may have a higher tolerance for (i.e., ability to deal effectively with) stressful situations. The SPAR-H method PSFs with the strongest degree of relationship are:

- *Available Time on Stress*—having less time available increases stress on the individual
- *Complexity on Time Available*—i.e., the complexity of the situation is a major determinant of whether or not the time available is perceived to be sufficient.

Further research in HRA could be focused toward developing the correlations that would be assigned to each of the interaction cells. SPAR-H does not attempt to quantify every aspect of PSF influences and relationships. We provide the above information to help inform the analyst in a qualitative way. It is premature to suggest how to model the interdependence of PSFs until more about these relationships is known. We realize that this area of research is a challenge germane to all HRA methods. During the course of conducting and documenting the analysis, the analyst always has the obligation to note important relationships that he or she observes.

2.7.6 The CNI Distribution

As mentioned, the CNI distribution used in the SPAR-H method is a special type of maximum entropy distribution. Entropy, in the case of HEPs, represents the expectation on the logarithm of the HEP distribution. As Atwood (1996) points out, if the HEP distribution has a finite range (which it does, bounded between 0 and 1), then the function that maximizes entropy is a uniform distribution. A limitation in *unconstrained* noninformative distributions is that the mean value of a uniform 0-to-1 distribution is 0.5. Consequently, the prior distribution, having a mean of 0.5, would tend to pull the posterior HEP distribution toward a mean value of 0.5. It was this limitation that motivated Atwood to develop the CNI distribution, where the constraint is that the prior distribution has a user-specified mean rather than a mean of 0.5.

The CNI is a single parameter distribution, which is the mean. Once the mean HEP is known, the analyst may use Atwood (1996) to determine an approximate distribution based on a beta distribution. The beta distribution requires two parameters, α and β. Atwood (1996) supplies a table of applicable α parameters (as a function of mean HEP). Figure 2-6 shows the numerical value of α as a function of the HEP. For example, using the SPAR-H worksheet, if one determines that the HEP has a value of 0.3, the value of α (from the curve) is 0.42. The second parameter, β, is found via the equation:

$$\beta = \frac{\alpha(1 - HEP)}{HEP} .$$

In the case where the HEP is 0.3, β is found to be 0.98. Now that both α and β are known, any analysis package containing a beta distribution may be used to determine the uncertainty distribution of the HEP. For example, within Microsoft's EXCEL spreadsheet, the 5^{th} percentile for the example HEP would be given by the command:

=BETAINV(0.05, α, β)

where the actual cell references to α and β are supplied in the command. Figure 2-7 plots the CNI distribution for a variety of mean values, ranging from 1E-3 to 0.8, to illustrate the span of the uncertainty distribution. For users of the SAPHIRE software, the only parameter that must be specified is the mean value, since SAPHIRE has been programmed to automatically determine the resulting associated beta distribution.

2.7.7 Combining Non-SPAR-H Information with SPAR-H

Occasionally, combining disparate sources of HEP information into a single HEP may be desirable. For example, combining two THERP-based actions, each with their associated lognormal distribution and error factor (EF), will result in a single HEP estimate. However, this estimate must then be recast into a format suitable for SPAR-H.

Specifically, we would need to determine an overall mean value and, possibly, information related to the uncertainty distribution (e.g., the standard deviation).

A common method of aggregating parameters that have uncertainty is to use the Taylor series expansion. The statistical moments (mean, variance, skewness, etc.) for the overall model are calculated by expanding the model equation in a Taylor series about the mean. What results from the expansion process is an equation for the overall statistical moments, which is a function of the variable moments and the partial derivative of the model equation.

Most statistical texts address the Taylor series expansion. Rather than presenting an inordinate amount of detail, only the results of the expansion process will be presented (Ang and Tang 1975). Furthermore, this report only illustrates two cases, when two factors are (1) additive (e.g., summing two HEPs into a single action), or (2) multiplicative (e.g., multiplying a nominal HEP by a PSF).

The approximate expected value and the variance of the overall HEP model are (to second order):

ADDITIVE – $\text{HEP} = \text{HEP}_1 + \text{HEP}_2$

$\text{Mean(HEP)} = \text{Mean}(\text{HEP}_1) + \text{Mean}(\text{HEP}_2)$

$\text{Var(HEP)} = \text{Var}(\text{HEP}_1) + \text{Var}(\text{HEP}_2)$

MULTIPLICATIVE – $\text{HEP} = \text{HEP}_1 \bullet \text{PSF}$

$\text{Mean(HEP)} = \text{Mean}(\text{HEP}_1) \bullet \text{Mean(PSF)}$

$\text{Var(HEP)} = \text{Mean(PSF)}^2 \bullet \text{Var}(\text{HEP}_1)$
$+ \text{Mean}(\text{HEP}_1)^2 \bullet \text{Var(PSF)}$

where Mean( ) is the mean value, Var( ) is the variance (recall that the variance is the square of the standard deviation). These derivations assume that the individual parameters are statistically independent.

The mean (or expected value) of the HEP equation is a function of only two terms (to second order accuracy). Additional HEPs may be included in the overall HEP, but the general form of the mean remains a summation of the individual means. The variance of the HEP equation is a function of only the variance (to second order accuracy) for the additive model and both the mean and the variance for the multiplicative model.

These approximate mean and variance equations may be used to determine the aggregate distribution characteristics when combining SPAR-H method and non-SPAR-H method information. Once the overall mean and the variance are known, one may simply use the mean value and select the CNI distribution, as advocated in Section 2.6.6.

Alternatively, one may use the method of moments to fit the approximate mean and variance to a beta distribution with that same mean and variance. For a beta distribution, X, we have:

$$\text{Mean(X)} = \frac{\alpha}{\alpha + \beta}$$

$$\text{Var(X)} = \frac{\alpha}{(\alpha + \beta + 1)(\alpha + \beta)^2} \ .$$

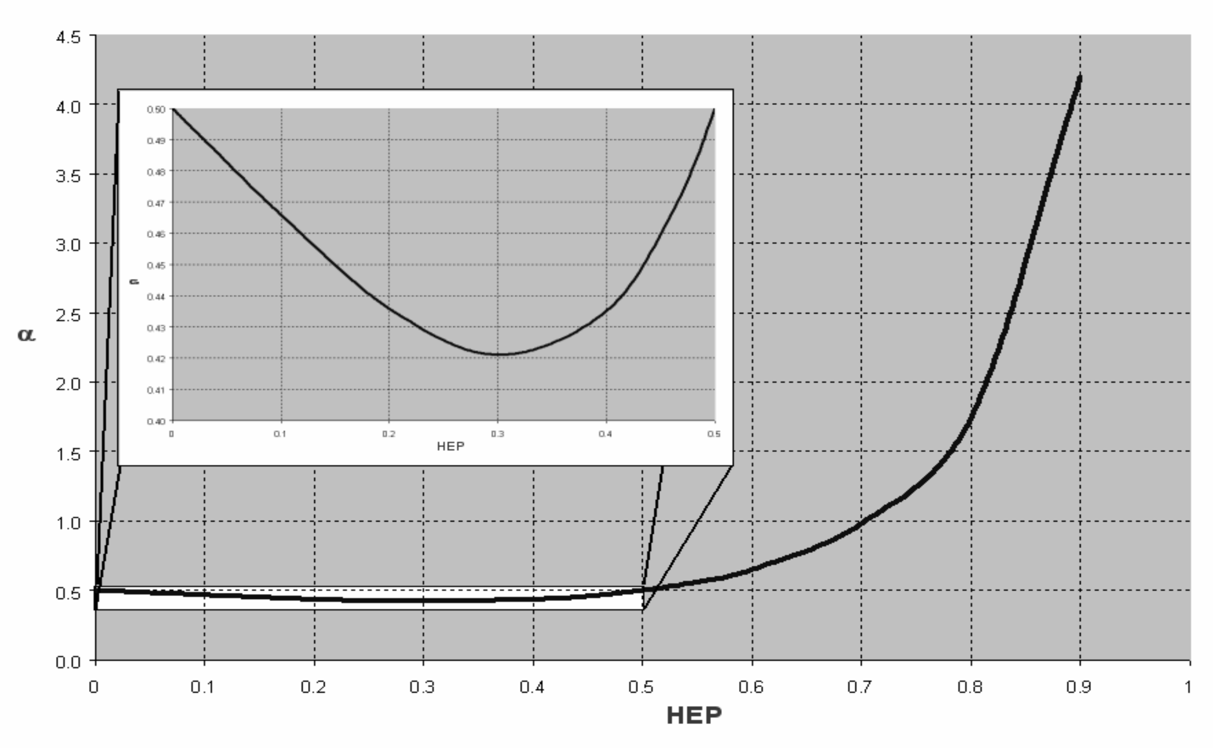

Figure 2-6. Alpha (α) as a function of mean HEP.

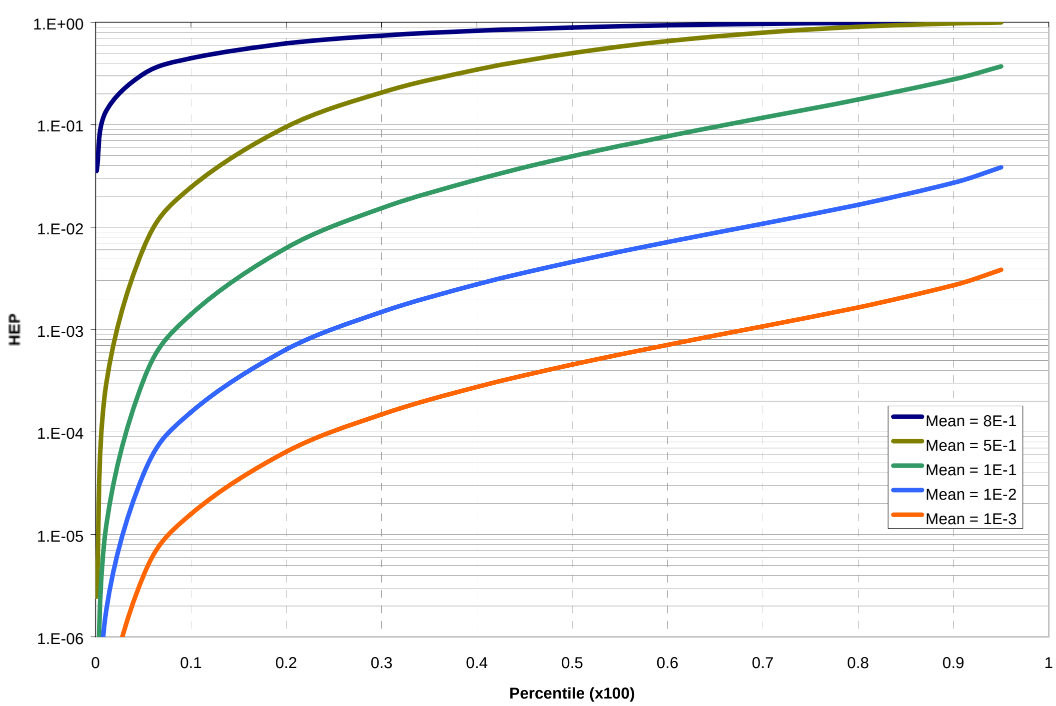

Figure 2-7. CNI distribution for the HEP.

While the approximate method described above is adequate for many cases, analysis tools such as SAPHIRE have mechanisms built in to facilitate model construction and analysis using Monte Carlo simulation. For example, one could simply identify individual HEPs as basic events and then sum those events using the *compound event* feature within SAPHIRE. The uncertainty on the individual basic events would then automatically be propagated though the model during the course of an uncertainty analysis. Nonetheless, the method described above is a generic applicability and may be used when needed.

2.8 Recovery

Recovery as used in PRA, generally describes restoration and reparation acts required to change the initial or current state of a system or component into a position or condition needed to accomplish a desired function for a given plant state (ASME RA-S-2002). In the SPAR-H method, restoration or reparation actions are modeled in the fault tree or event tree logic structure used by the analyst. Therefore, the burden to account for recovery within fault tree logic structure lies with the analyst.

This is in contrast to THERP, where review by second checkers, supervisors, or appearance of a second crew has a discrete value and can be used to modify a nominal HEP. This is not the same definition of recovery as system restoration or reparation as used above. THERP explicitly accounts for *error recovery* in situations where additional steps in procedures can indicate the error and help to formulate the correct response, and where expected, required periodic control room scanning or system walkdowns can help to indicate misdiagnosis. The nominal HEP may also be reduced when a new, salient alarm is activated. Implicit in this approach is the notion that errors in diagnosis may be corrected as a function of additional alarm information, i.e., an additional alarm can be thought of as an increase in cue strength. In SPAR-H, the analyst has two means by which to represent these potential influences on HEPs. The first is to perform more detailed modeling. The second, and suggested approach, is to make adjustment to the nominal HEP by assigning the appropriate positive levels to the appropriate subset of PSFs. In the above example, the work practices PSF (for additional personnel being present), procedures PSF (if additional steps strongly indicate to the operator that misdiagnosis has occurred), and ergonomics (for new alarms that will strongly shape the operator or crew sense that misdiagnosis has occurred) can be used by the analyst to indicate that these factors are likely to produce a situation where the nominal value for diagnosis is overly conservative.

The current approach allows the analyst to account for as many recovery combinations or opportunities as warranted, and suggests this consideration to be explicitly modeled in the logic structures.

Once the appropriate level of modeling has been determined there are a number of questions the analyst should pose regarding functional recovery. They appear in Wakefield et al. (1990), who suggest the analyst ask:

- Can the crew diagnose the need for recovery?
- Can it be accomplished in the time available?
- Can the equipment be put in functional condition by personnel?
- Can the crew gain access to the equipment?
- Are the required staff (with the right skills) available?

3. ANALYSIS

3.1 Base Rate Comparison Among HRA Methods, Including SPAR-H

To calibrate the SPAR-H method against other HRA methods, the base failure rates associated with a number of contemporary HRAs were compared. Table 3-1 compares error rates for operator or crew actions. Here the SPAR-H method base rate is toward the lower end of the rates associated with other methods. The difficulties of comparison due to PSF entanglement in the descriptions may be even more of a problem in this comparison. Because of this difficulty, the 1994 ASP validation, and the firm belief of the analysts that the difference between the diagnosis and action base rates needs to be maintained, no change in this base rate was made at this time. Future full-scale benchmarking of HRA method against method could help to resolve this issue but, resources may be better directed toward HRA data collections, so that a better basis for rates underlying HEPs might be determined.

Table 3-2 compares mixed rates. That is, the table shows rates for error types whose descriptions partake of both diagnosis and action (or where a distinction cannot be made.) The difficulties in making comparisons among these rates make this primarily an information table, included for completeness. One method, FRANCIE (Haney 2002), not mentioned previously in this report, was developed for NASA primarily as a qualitative human error analysis method, dependent on analyst characterization of a large number of PSFs. The method allows for quantification, and a number of values from this source were included in this broad characterization of mixed base rates available from HRA methods.

The SPAR-H method base rates for diagnosis and action were not changed. Since the various methods compared use different base rates, with different PSFs, with different levels of influence, direct comparison of method rates is difficult.

Table 3-3 presents diagnosis error type base rate comparisons, which compare the SPAR-H method diagnosis base rate to the base rates for diagnosis in other HRA methods. For completeness, this table includes the INTENT HRA method (Gertman et al. 1992).

These comparisons are still difficult, due to the differences in definition and the incorporation of PSFs into many of the descriptions (e.g., ASEP, HEART). As in contemplating base rate comparisons for operator actions as a function of HRA methods, a more robust comparison of the base rates could take place via a benchmarking exercise.

Table 3-1. Action error type base rate comparison.

Method	Error Type Description	Base Rate (5^{th} – 95^{th} percentile bounds)
SPAR-H	Action Task	0.001
HEART	D. Fairly simple task performed rapidly or given scant attention	0.09
	F. Restore or shift a system to original or new state following procedures, with some checking	0.003
CREAM	Tactical	0.001–0.1
ASEP	Table 7-3. Screening critical action, assuming moderate stress, and no recovery.	0.05
THERP	Table 20-2 Rule based actions of control room personnel after diagnosis, with recovery. EF=10	0.025

Table 3-2. Mixed-task base rate comparison.

Method	Error Type Description	Base Rate
SPAR-H	Task involving both diagnosis and action	0.011
HEART	A. Totally unfamiliar, performed at speed with no real idea of likely consequences	0.55
	B. Shifts or restores system to a new or original state on a single attempt, without supervision or procedures	0.26
	C. Complex task requiring high level of comprehension and skill	0.16
	E. Routine, highly practiced, rapid task, involving a relatively low level of skill	0.02
	G. Completely familiar, well-designed, highly practiced, routine task occurring several times per hour, performed to highest possible standards by a highly motivated, highly trained and experienced person, totally aware of implications of failure, with time to correct potential error, but without the benefit of significant job aids	0.0004
	H. Responds correctly to system command, even when there is an augmented or automated supervisory system providing accurate interpretation of system state	0.00002
	M. Miscellaneous task for which no description can be found (Nominal 5th to 95th percentile data spreads were chosen on the basis of experience available suggesting log normality)	0.03
FRANCIE (5th-95th percentile)	1. Procedural Omission	0.0059
	2. Error of Intent	0.085
	3. Selection Error	0.015
	4. Awareness and Task Execution Related to Hazards/Damage	0.016
	5. Cognitive Complexity or Task Complexity Related	0.033
	6. Inspection/ Verification	0.097
	7. Values/Units/Scales/Indicators Related	0.022
	8. Maintenance/Repair Execution	0.041

Table 3-3. Diagnosis error type base rate comparison.

Method	Error Type Description	Base Rate
SPAR-H	Diagnosis Task	0.01
CREAM	Tactical Control Mode	0.001–0.1
	Opportunistic Control Mode	0.01–0.5
ASEP	Table 7-2. Screening diagnosis, assumed to be under moderate stress, given 30 minutes. EF=10.	0.01
THERP	Table 20.1 Screening diagnosis. EF=10.	0.01
HEART	Miscellaneous task category “M”, no description in other tasks (A-H) fits diagnosis tasking as well.	0.03
INTENT	Misdiagnose given like symptoms. Capture sequence based on stimuli.	0.057
	Competing goal states lead to wrong conclusion.	0.048
	Symptoms noticed, but wrong interpretation.	0.026

It is important to note that the SPAR-H method diagnosis base rate of 0.01 is within the same general range encompassed by the rates for each of the other methods. Given this and the difficulty of comparison, and the fact that the base rate had some initial validation in the 1994 SPAR-H method, no change in the diagnosis base rate was made.

As a result of the PSF comparison detailed in Section 3, as well as additional reviews conducted, the following PSFs, presented in Table 3-4, require assessment as part of the SPAR-H method (2004 revision) quantification process. Note that the number of levels associated within a particular PSF is, for the most part, the same for action or diagnostic tasks. The exception is "complexity," where, in the case of diagnosis, complex scenarios were more challenging for analysts to evaluate, and the addition of a level was found to allow them greater flexibility and confidence in their estimate(s).

Section 3.2 presents general definitions used to assist analysts' evaluation of PSFs. Applications to operating events demonstrating the assignment of PSFs are contained in Appendix F of this report. A brief discussion of the occurrence of SPAR-H method PSFs in events follows here.

Review of PSFs selection against operating events. The PSFs in the SPAR-H method are addressed in the behavioral sciences literature, and *fit* with the information processing model of human behavior presented in earlier sections of this report, and are present in other HRA methods.

As an additional check on the validity of selecting these PSFs, the INL reviewed operating event analyses present in the NRC Human Performance Event Data Base (HPED) and attempted to identify instances in which effects of the SPAR-H method PSFs could be defined. The HPED contains human factors analysis and identification of PSFs culled from review of licensee event reports (LERs) and augmented inspection team (AIT) reports. Also included in the HPED is information about the data source, general event information, description of contributing factors, personnel and personnel response during the event, and coding of factors such as communication and command and control influences. A total of 196 records are contained in the database; 66 of those are from AIT sources; 42 are from LERs that correspond to ASP events. In instances where information was too incomplete for assigning different PSF levels, the authors reviewed the original LER or AIT sources.

Thirty-six event summaries were coded against the eight SPAR-H method PSFs and their associated levels of influence. Most levels of influence were present in one or more of the events contained in the HPED database. Others were simply not reported. For example, LERs typically would not report that nominal time was available, or that expansive time was available. This does not mean that these levels of available time PSF do not

Table 3-4. SPAR-H PSFs used in quantifying HEPs.

PSF	Diagnosis Levels	Action Levels	Range of Influence
Available time	5	5	.01 to failure
Stress/Stressors	3	3	1 to 5
Complexity	3(4)*	3	0.1 to 5
Experience/Training	3	3	0.5 to 3
Procedures	4	4	0.5 to 50
Ergonomics/HMI	4	4	0.5 to 50
Fitness for Duty	3	3	1 to failure
Work Processes	3	3	0.8 to 5
*The number in parentheses = the number of levels associated with LP/SD			

occur, but rather, on average, PSF information tends to be reported when negative. Another example of this is stress. Moderate or normal stress is not explicitly called out in reports. The negative influence associated with high stress in personnel performance tends to be addressed. For example, the report for the Zion Nuclear Station (U.S. NRC 1997) shutdown event identified that a large number of people in the vicinity of the control room, combined with high ambient noise, and concurrent attempts at pump restoration all contributed to a high level of stress. This stress, in turn, contributed to improper reactivity control via poorly coordinated control rod movements. This analysis, which provides evidence of SPAR-H method PSFs in high profile events, is presented in Appendix F. In general, it further supports the PSFs present in the SPAR-H method.

3.2 Comparison of PSF Weights for Low Power Versus At-power

Internationally, groups such as COOPRA have sought to simplify, and by sharing information, help to standardize approaches/activities supporting LP/SD PRA. LP/SD and at-power conditions are generally recognized to be different (more variable in the case of low power, for example), although they are potentially as risk significant as many of the operations performed at power (Gertman et al. 1996). For example, direct fuel damage and or interruption of decay heat can be considered as initiating events for LP/SD conditions. Heavy load drops can have a human initiator, as can erroneous draining of an operation loop.[4] Currently, the NRC SPAR program has been developing LP/SD models to support the analysis of operating events

Therefore, reviews were conducted to characterize, evaluate the potential influence of LP/SD upon human performance, and determine whether different PSFs were required to characterize LP/SD, or if PSFs with a different range of influence or different weights than those currently used in SPAR-H were required. An additional level of influence for procedures was identified, and the definitions for PSF levels associated with available time were revised. Some of the more important differences noted during this review are presented in Table 3-5.

As a result of this review, changes to two PSF influence categories, procedures and time available, were implemented. No basis for change in definition or range of effects for the other PSFs was identified.

After the review, an assessment was made to determine whether the changes suggested in the revision would result in:

- Different values when both sets of weights were applied to the same scenario
- Analysts finding the revised LP/SD worksheets easier to apply to LP/SD conditions
- A greater face validity and corresponding analyst confidence when compared to the HRA worksheets developed for at-power.

An analysis team consisting of an HRA specialist and two operations specialists conducted an application to an LP/SD scenario. HEPs were calculated, and comparisons were made when applying the two types of worksheets. Based on field test findings, the assignment of an additional level of procedures PSF was made to both the at-power and the LP/SD worksheets. Also, based on these findings, actions for both worksheets used the same multiples of available time (i.e., greater than five times nominal and greater than 50 times nominal) to assign the appropriate PSF level of influence. Therefore, the worksheets used in the evaluation differed primarily in one category, the way that time available was expressed for diagnosis. Diagnostic tasks are more time sensitive and the range and level of effect are therefore different between action and diagnosis. For example, the amount of time available during LP/SD for activities, including diagnosis, varies widely and generally may be less uniform than the typical response time associated with conditions guided by emergency operating procedures (EOPs) during at-power.

[4] SPAR-H has been used to support NRC screening analysis of human-induced heavy load drop, fuel misleading, and other significant actions for LP/SD conditions

Table 3-5 Assumed differences among LP/SD conditions and at-power mode.

At-power Mode	LP/SD Conditions	Comments
Well trained to, well defined initiating events may apply.	Different initiating events may apply.	For example, there may be some procedures induced loss of coolant accidents possible during LP/SD conditions.
More safety systems available.	Different safety systems available.	
Refueling and mid loop operations not a concern.	Refueling operations, mid-loop operations, and draindown are different than at-power evolutions and are performed less frequently.	Level control at mid-loop operations is of concern.
Transients are consistent in nature and operators more practiced in their response.	Transients are less consistent; operators in control room and others do not practice simulator training for LP/SD activities.	
Stricter limits for required operable safety systems (how many systems can be down for maintenance and repair).	Limits are less strict, greater number of systems are down for maintenance and repair.	
Lower diversity of equipment configurations and operability.	Higher diversity of equipment configurations and conditions for operability.	Keeping track of conditions much more demanding. Different operations such as spent fuel pool handling operations important.
Hardware contributors most likely contributors to initiating events.	Human errors may be more likely contributors to initiating events.	Multiple crews, multiple activities, incomplete or infrequently used procedures
Only 1–2 train(s) of ECCS allowed *to be inoperable*—as many as 6 or 7 (counting ADS) allowed to be inoperable.	Only 2 trains are required *to be operable* (4 allowed to be inoperable).	Varies from plant to plant, set forth in Technical Specifications.
Fewer work activities performed.	Greater amount of work activities being performed such as tests, maintenance, and repairs.	Greater complexity may be present during LP/SD operations.
Expected equipment configurations the norm.	Different equipment configurations are often times the norm.	Less frequently performed operations.
Breached containment not allowed.	Breached containment allowed under certain restrictions.	Restrictions may conflict with other desired shutdown evolutions, such as fuel movement.
Predictable workload during normal at-power conditions.	Variable, perhaps unexpected, workload shifts during normally occurring shutdown conditions.	
Most activities are formally practiced and are heavily proceduralized.	Many of the procedures being followed consist of work orders, are more custom, are more diverse, and in many cases have not been tested. Use of mock-ups and practice of major activities, especially in radiation areas is often performed. Not as clear for non-radiation areas.	Example, leak in section of PCS sampling system, but no procedure for every mile of pipe and elbows exists. Procedure must specify order of opening and closing valves to isolate before welders can come in. All testing and equipment lineups, including what systems must be in place to conduct tests, etc. This will be specific to the area being evaluated. Installation of temporary bypasses or modifications is specified in the work order. None of this will be highly practiced, compared to startup and shutdown procedures on which operators are tested and trained.

Often, tasks may not be fully proceduralized during LP/SD or, in some instances, only partially complete procedures are available. Since this may be the norm, and workers often can complete their assignments without undue high error rates, the SPAR-H method approach to procedures was re-examined. As a result, an additional level for the procedures PSF was generated for LP/SD. Formerly, if procedures did not exist, the SPAR-H method would assign a multiplier of 50 to the base failure rate. Another level corresponding to limited or incomplete procedures with a multiplier of 20 has been added to give HRA analysts additional flexibility to more accurately determine HEP estimates. Also, the influence and or availability of procedures as conceptualized in THERP and other methods did not fully include characterization of LP/SD situations, or other situations where skill of the craft is such that it routinely overcomes the effects of limited or partial procedures. Making it easier for analysts to determine the range of influence of procedures effect was so successful that this additional level for procedures effect was also adopted for use in the at-power HRA worksheets.

The information contained in Table 3-5 suggests how to redefine or renormalize the PSFs when evaluating the departure of conditions from the nominal case. That is, evaluation of deviation for LP/SD PSFs should be conducted against what is expected for LP/SD conditions and not necessarily for what would represent nominal conditions for at-power. This is the primary reason two sets of the SPAR-H method worksheets were developed.

Limited field-testing at NASA and interviews with human factor analysts also indicated that for normal operations in other domains, the inclusion of an additional level of procedures made assignment of PSF weights less difficult for analysts. As a result, an additional level was added to the procedures PSF for both the at-power and LP/SD HRA worksheets. The range of influence for the procedures PSF was not changed, and falls within the range of influence indicated by other HRA methods.

3.3 Approach to LP/SD Comparison

Table 3-5 suggested a number of differences between LP/SD and at-power. It was assumed that this might go beyond conceptualizing a generally different set of conditions and lead to separate SPAR-H method worksheets, with possibly different levels of PSFs or different PSF ranges.

LP/SD HRA worksheets were developed and are presented in Appendix B.

In order to determine whether there was a difference in HEP results when analysts used the LP/SD HRA worksheets (i.e., PSF weights versus using the at-power worksheets), a comparison of the two types of worksheets was made. This comparison was performed as follows:

1. Operations and human factors analysts separately reviewed an LP/SD event sequence and then applied the set of PSF weights (referred to as Weight Set A) used when calculating HEPs for at-power operations.

2. They subsequently performed the same review and applied the forms revised for LP/SD scenarios, which included LP/SD-specific weights (Weight Set B).

3. The analysts then determined the differences between the two resulting sets of HEPs. These results are shown below in Table 3.6.

Weights. Using the at-power PSF weights resulted in three out of nine HEPs (33%) associated with the loss of inventory (LOI) scenario receiving a higher failure rate when compared with HEPs determined with LP/SD weighting factors. The analysis team indicated that they were more comfortable with the LP/SD weights, and that the LP/SD resultant values were more consistent with operating experience.

Categories. In all instances, the improvements to the categories associated with time enabled analysts to assign influences that better approximated their experience. The values assigned were within the range of influence, as determined by review of HRA methods. Operator performance in the three tasks (failure to initiate

Table 3-6. Loss of inventory with RCS pressurized HEPs Comparison of PSF influence for PSF Weight Sets A and B

HEP Number and Description	HEP_{psfa}	HEP_{psfb}	Change Ratio
1. Failure to diagnose loss of inventory	0.05	0.05	1
2. Failure to Initiate RCS inventory makeup	0.005	0.0005	10 to 1
3. Failure to terminate loss of inventory	1.0	1.0	1
4. Failure to recover RHR	0.00025	0.00025	1
5. Failure to re-establish RCS flow	0.003	0.003	1
6. Failure to perform secondary cooling	0.002	0.002	10 to 1
7. Failure to force feed	0.004	0.004	1
8. Failure to perform feed and bleed	0.001	0.001	1
9. Failure to establish long term re-circulation	0.002	0.00002	10 to 1

reactor coolant system, failure to perform secondary cooling, and failure to establish recirculation) all benefited from the extended time horizon available to crews.

Although the HEPs obtained when using different PSF weights are obvious, the impact of the differences upon plant risk cannot be determined without accounting for the context potential of these failures and subsequent changes in the conditional core damage probability (CCDP). Other samples of tasks taken from different scenarios may result in different reduction ratios or similar ratios with different impacts, depending on the initiating event sequence.

3.4 Additional Field Testing

SPAR-H method (2004 revision) At-power HRA worksheets were subject to limited field-testing at the NASA Johnson Space Center (JSC). In conjunction with implementation of human performance assessments, including human factors process failure modes and effects analysis (HF PFMEA), three JSC processes were selected, and a subset of tasks from each process was subjected to a SPAR-H method evaluation. The selected processes were the J-85 engine refurbishment task, self-contained breathing apparatus (SCUBA) tank refilling operations, and assembly of exercise equipment required for the international space station.

The SPAR-H method produced HEPs whose likelihood followed the same general pattern of that determined as part of process FMEA. The analysts were four human factors professionals who had a brief training session devoted to the SPAR-H method during INL visits to JSC under another project. The JSC analysts found the screening process to be easy to use. They stated that, while the range associated with the procedures influence category was sufficient, an additional level for negative influences would make the assigned PSF weight more realistic. They also reported some subjectivity in the approach, but noted that it probably was more objective than the FMEA approach that they were testing concurrently. They also reported that conceptualizing factors such as error type, PSFs, recovery, and dependency caused them to gain insights regarding performance that they were able to convey to operations personnel.

3.4.1 Applicability of the SPAR-H Method to External Events

While the focus of this report is the SPAR-H method as specifically applied to at-power and LP/SD HEP determination, the heuristics described herein may apply to other situations. For example, the SPAR-H method may be applicable to external events such as fire, flood, seismic, and other special failure events such as partial failures, containment impacts, and plant physical security.

When applying the SPAR-H method to potential scenarios representative of a variety of situations, one should consider features specific to these additional situations. For example, an external event may occur during either at-power or LP/SD operations and may occur during a transition of plant operational modes. Furthermore, the PSF impacts for an external event scenario may vary dramatically from one case to another (e.g., a flooding event may have a long-term duration, while a fire event may have a very short duration). While there is no reason to believe that base failure rates or the set of PSFs used in the SPAR-H method would need to be changed for such analysis, it is possible that the PSF multipliers are not applicable for these additional situations due to their unique character and infrequent realization. To better reflect an applicable HEP, it may be necessary to investigate the driving mechanisms within situations, such as external events. While this work is outside the current scope, we believe that it would be possible to address the applicability of the SPAR-H method to external events and special failure events as a part of future development activities.

3.5 Range of Uncertainty Associated with HRA Methods

3.5.1 Evaluation Against Other Methods

The INL examined other HRA methods and the range of uncertainties employed by those methods. The other methods examined [THERP, ASEP, HEART, CREAM, CAHR, and the Surry Low Power and Shutdown PRA (NUREG/CR-6144)] actually set forth HEPs and uncertainty bounds (as opposed to methods that call for expert judgment of uncertainty bounds). Although HEART and CREAM set forth uncertainty bounds rather than error factors, we converted these bounds to approximate error factors for convenience of comparison.

These other methods were examined for error uncertainties in both diagnosis and action tasks—the two error types that the SPAR-H method uses. For example, only two HEART tasks were deemed by the analysis team to be purely action tasks, whereas the rest of the HEART tasks were determined to be a mix of diagnosis and action.

Table 3-7 shows the error factors from the other methods compared to the SPAR-H method error factors. Overall, we observed convergence in error factors. (We postulate that this convergence represents the seminal influence of THERP).

The analysis team had postulated that additional uncertainty is present in LP/SD conditions. This is because of more direct human-system interaction, less developed procedures, changing plant configurations, unique combinations of unusual plant vulnerabilities, and the increased probability of mistakes and errors of commission (see NUREG/CR-6093).

However, even though it was possible to create error factors consistent with other HRA methods, situations still resulted where the upper bound associated with HEPs could exceed 1. The analysis team decided to adopt a Beta distribution, as discussed in Section 2.7.6. The information in this section is presented for archival purposes and to inform readers regarding uncertainty as expressed in other HRA methods.

3.5.2 Change of Distribution Due to Truncation

The earlier versions of the SPAR-H method truncated point estimates of HEPs at 1. However, in the use of uncertainty distributions, good practice may dictate that, if the uncertainty results in a portion of the distribution are greater than 1.0 or less than 0.0, modification of the distribution is appropriate. (Revision to distributions is considered in Section 2.7.6 of this report.)

The lognormal distribution is a poor choice for probabilities near 1.0 because it is skewed with a long tail on the right. An alternative approach using beta distributions is presented, and we encourage using this method.

3.6 Change in Time PSF

Based on reviews, a major change was made to the approach used previously (1994) to estimate the influence of time on operator diagnosis and action. Briefly, this entails a change to the time horizon, where it was determined that for actions, minutes were not as appropriate a measure as was a multiple beyond the nominal time. For five times the nominal time required, HEPs are reduced by 0.1. For situations in which the time available is

Table 3-7. Diagnosis and action error factors as a function of HRA method.

Methodology	Diagnosis Error Factors [HEPs]	Action Error Factors [HEPs]	Mixed Uncertainty and Associated HEPs	Comments
THERP Screening	5(0.5), 10(0.1, 0.01, 0.001) 30(0.0001)	10(0.05, 0.025)		Screening Diagnosis - 5 for 10, 10 for 60 and under, 30 for 1 day Screening actions - 10
THERP	10 (0.1, 0.01, 0.001) 30 (0.0001, 0.00001)	3(0.001 to 0.01), 5(0.003 to 0.5) 10(0.0005 to 0.005)		Larger EFs are used for HEPs smaller than 0.001 to reflect the greater uncertainties associated with infrequently occurring events. Nominal diagnosis - 10 for 30 and under - 30 for 60 and above 3 for skipping a step, for recalling oral instruction, reading and recording, check reading, 10 for using procedures in abnormal operating condition
ASEP Post Screening	5(0.5) 10(0.1, 0.01, 0.001) to 30 (0.0001)	5(0.01, 0.05, 0.25)		
ASEP Post	10(0.1, 0.01, 0.001) 30(0.0001, 0.00001)	5(0.02, 0.05, 0.25, 0.2, 0.5) 10(0.001)		
CREAM	Mostly 10 (one 3 for higher HEP)	Mostly 3 (one 10 for lower HEP)		Approximate, since actually given as lower bound (LB) and upper bound (UB), expert judgment uncertainty bounds given for specific cognitive function failures given in Table 9, Chapter 9. Unspecified "established data sources" for proceduralized behaviors such as observation and execution, mostly expert judgment for interpretation and planning. Error factors from 1.3 to 10 Expert judgments in Fujita and Hollnagel (2002)
HEART		1.5 to 3	1.5 to 45 (Very asymmetric for very low HEPs)	Approximate, since actually given as LB and UB data based 5th and 95th percentiles are defined for the generic tasks and used in the normal HEART calculation to produce bounds
CAHR	Similar to THERP	Similar to THERP		Per Personal Communication from O. Sträter. Applied Bayesean update to data from incident data base and then transferred into HEPs using Rasch model. Coincidentally, these values are in the same range as THERP.
NUREG/CR 6144	20 (x > 0.000001; < 0.0001)	5(x < 0.001) 3(0.001 < x < 0.1) (0.1< x)		For Action (A), Recovery (R), and Diagnosis (D) events, uncertainty follows a lognormal distribution.
SPAR-H	10	3		Approach changed in 2003.
SPAR LP/SD	10 (0.001>x) 20 (x<0.001)	5		Approach changed in 2003.

50x the nominal time required, HEPs are multiplied by a factor ranging from 0.1 to 0.01. Selection of the multiplier (e.g., 0.01) is up to the analyst's discretion. This is true for both LP/SD and at-power scenarios.

For diagnosis, time is considered differently. For at-power, extra time is assigned a multiplier of 0.1, expansive time (i.e., greater than 24 hours) is assigned a multiplier of 0.01. For LP/SD conditions, extra time is defined as less than or equal to two times nominal; expansive time is defined as greater than two times nominal. This reflects: (a) the analyst's greater uncertainty in assessing time available during LP/SD, and (b) LP/SD situations where, unlike at-power scenarios, time has such a wide range that it is more logical to speak of multiples of this time than to try to assign a single estimate. In estimating the influence of expansive time, analysts should make use of structured expert estimation methods such as those referenced in ATHEANA (NUREG-1624 2000). The new structure for this PSF for diagnosis and actions is listed in Table 3-8.

By eliminating the assessment of specific times, which is difficult for LP/SD situations, the analysts are allowed to estimate a range rather than a specific value. Table 3-9 presents hypothetical examples of how using the range for expansive time can be applied to address the influence of time for different situations surrounding two basic events associated with LP/SD. The other two examples address the influence of time upon diagnosis during an LP/SD event.

Time Advantage. Having three times the amount of time it normally takes the operators to place the system in service gives the operators more time to recover from their own errors, to troubleshoot, realign misalignments, and communicate with others outside the control room, such as auxiliary equipment operators that may be required to perform local manipulations, and, during emergencies, personnel staffing, the Technical Support Center (TSC), and Emergency Operations Center (EOC).

Further Assumption(s). It is further assumed that infrequently performed, difficult diagnoses (of a problem) will benefit more greatly from additional time than will routinely performed diagnoses. Complex, infrequently performed actions such as unique evolutions may also benefit from additional time. However, previous HRA approaches have narrowed the definition of time for diagnosis by use of minutes. This may correspond to expected crew performance under at-power conditions. Use of a nominal estimate, given the context, appears to be more meaningful. In general, additional time

Table 3-8. Available time PSF influence for LP/SD.

LP/SD Available Time for Diagnosis	Inadequate time	P(failure) = 1.0	**Notes:** * Analyst's choice, depending on complexity of diagnosis, including multiple factors such as available help and likelihood of additional cues. ** Analyst's choice, depending on complexity, PPE, work environment, and ease of checking and recovery.
	Barely adequate time (approximately 2/3 x nominal)	10	
	Nominal time	1	
	Extra time (between 1 and 2 x nominal)	0.1	
	Expansive time (>2 x nominal)	0.1 to 0.01*	
LP/SD Available Time for Action	Inadequate time	P(failure) = 1.0	
	Time available is approximately equal to time required	10	
	Nominal time	1	
	Time available is ≥ 5x the time required	0.1	
	Time available is ≥ 50x the time required	0.01**	

Table 3-9. Influence of expansive time on base failure rates.*

Item	Event Description	Complicating Conditions	Influence of Expansive Time	HEP reduction factor**
1	Diagnose Loss of Inventory	Small leak with concurrent loss of 125 volt instrumentation power complicates diagnosis.	High	0.01
2	Diagnose Loss of Inventory	Small leak, no adverse or complicating conditions.	Very low	No reduction, Nominal
3	Establish Residual Heat Removal Recovery	Loss of bus leading to loss of power to shutdown cooling.	High (Additional time allows for jumpering of leads, etc)	0.01
4	Establish bleed	Loss of bus leading to loss of power to shutdown cooling.	Low (Bleed can be performed across multiple systems, single bus assumed not to cut across a great number of these systems)	0. 1

* As applied to potential basic events for a pressurized water reactor (PWR) LP/SD Scenario, loss of inventory (LOI) with RCS pressurized.

** Value multiplied against the base error rate for available time PSF.

may be expected to be beneficial in complicated shutdown situations involving diagnosis.

The four events in Table 3-9 represent basic events that could occur in various LP/SD sequences. In general, increased pressure will result in increased loss of inventory over situations where the reactor coolant system is not pressurized. Two events correspond to diagnosis of this loss of inventory (LOI) sequence. In the first instance, a small leak with concurrent loss of 125-V instrumentation is postulated. The concurrent instrumentation fault increases complexity for the crew and complicates the diagnosis. Expansive time in this situation is likely to allow for the crew to achieve the proper diagnosis.

In the second diagnosis basic event, there are no complications, and in most situations the crew will have ample time to make the correct diagnosis. In this instance having expansive time will not appreciably change the outcome.

In the third basic event, as part of response to LOI, the crew must establish residual heat removal. This is made more difficult by the occurrence of a second fault, loss of bus leading to loss of power to shutdown cooling. The advantage of expansive time is that it allows for additional activities such as jumpering of leads inside of cabinets, coordination between auxiliary operators and the control room, etc.

In the final example, the crew must establish bleed after LOI, with the additional complication presented in basic event 3, loss of bus leading to loss of power to shutdown cooling. In this situation, the influence of expansive time is thought to be relatively low. Bleed can be performed across multiple systems, and a single bus failure will most likely not affect a great number of these systems.

Additional Discussion. Most PSFs were easily assigned across domains (i.e., LP/SD and at-power). In general, bad procedures are bad procedures, high stress is high stress, and their influence can be assessed for any domain of interest. The context may influence whether or not a certain level of stress has been reached and the extent of the influence for stress or other PSFs remains influenced by other PSFs as well.

Complexity ratings for diagnosis tasks executed during LP/SD employ an additional level for situations where the diagnosis is obvious. The multiplier associated with obvious diagnosis is 0.1 and was determined after reviews with systems analysts and license examiners at the INL.

4. USING SPAR-H

4.1 Modeling Conventions and Considerations

SPAR-H does not go into detail regarding conventional modeling considerations, such as level of decomposition, or provide guidance for aggregating different types of subtasks to facilitate analysis. These items are situation and analyst specific. Also, the PRA accounts for initiating event frequencies, combinations of hardware unavailability factors, and plant configuration factors thought to have a large influence upon plant risk. Differences in HRA estimates due to differences in task decomposition are thought not to result in large changes in the effects of HEPs on the overall risk estimate. The consistent use of the worksheets, the consistency of decomposition within the same HRA, and thoughtful assignment of PSF levels are of importance. However, a number of questions posed by users necessitate further explanation of certain SPAR-H modeling factors.

Using the SPAR-H worksheets, basic events can be determined in one of two ways. First, if the action being considered is clearly an action with no significant diagnosis activity, then the action page of the worksheet can be used, and the relative effect of PSFs detailed on the worksheets can be used to modify the nominal failure rate. Then the dependency formula addressing the influence of a previous basic event (HEP1) can be taken into account. Below is a hypothetical example, where the HEP2 for Action 1 is of this type.

IE	D	A1	EQ	R
Initiating Event	Diagnosis (HEP1)	Action 1 (HEP2)	Activate Equip-ment	Recovery (HEP3)

In performing the calculation, a straight multiplicative approach is employed, where the action HEP (0.001) is modified for applicable PSF levels. In computing the cutsets, the analyst will convert the initiating event frequency into probability and then multiply by the diagnosis HEP x the Action HEP x the calculated failure rate for equipment activation x recovery by the crew.

However, it may be the case, as in our example, that recovery consists of two aspects: diagnosis of the need to supply power to particular equipment and the need to configure valves for a lineup and then activate. In this instance, we have a joint HEP for diagnosis and action. These individual diagnosis and action elements constituting the joint HEP are not on the same level as the event sequence. Their combined contribution to the failure to restore (HEP3) is additive (OR) gate. Therefore, after they have been computed separately they are added together to = HEP3. HEP3 is then evaluated for dependency associated with previous basic event(s). This estimate is, in turn, multiplied by the HEP1, HEP2, EQ, etc., when determining cut sets. For our example above:

RECOVERY HEP3 = (HEPREC $_{\text{diagnosis}}$ + HEPREC$_{\text{action}}$).

This is similar to working on a fault tree level in order to determine the HEP for the basic event level.

To some, we may be somewhat conservative in our approach by virtue of suggesting within a single HEP (not necessarily on the event level) that if you fail to diagnose, then you most probably will fail to act appropriately (within time, correct action, action not too long, or too strong, etc). In other words, without diagnosis, action is much less likely. The action element of the joint HEP does not act like a second checker, an extra alarm, or some other type of redundancy or defense in depth to reduce the failed diagnosis portion of the HEP. In the SPAR-H approach to calculating the basic event that is a joint HEP, we do not allow for acting without considering diagnosing. If diagnosis is not needed, it is questionable to model it. There are situations where operators may just follow the procedures rather than reach a diagnosis per se. In this case, the action has its own HEP. Also, for those situations where the analyst believes that procedures, training, or indication can enable the crew to recover from a poor diagnosis, at least two modeling options exist: (1) the action portion of the joint HEP can be adjusted on the basis of these positive PSFs, or (2) the diagnosis and action elements can be modeled separately on the basic event level.

4.2 At-power

4.2.1 Prerequisites

Before using the SPAR-H method, the analyst needs considerable knowledge of the tasks and contexts to be rated. To this end, part of the ATHEANA (NUREG-1624) HRA process is described below, as an example of a structured method to obtain the kind of knowledge needed before the SPAR-H method may be used. The process described is the ideal situation. In building SPAR models, resource limitations, including access to utility trainers and operators, will often preclude complete ATHEANA-like applications. ATHEANA has the following advantages: its search process is rigorous, it differentiates among unsafe acts and human failure events (HFEs), and it acknowledges the importance of PSFs and context. Unsafe acts are usually modeled in fault trees and support the refinement and quantification of human failure events (HFEs). Human failure events often correspond to basic events in the PRA model. Other HRA approaches include SHARP and SHARP1, IEEE 1082, and ASME RA-S-2002, all of which can provide an overview of the HRA process.

4.2.2 ATHEANA Search Process

The ATHEANA HRA offers a ten-step search process compatible with PRA. This approach deviates from most first-generation HRA approaches (such as THERP, ASEP, HCR) in that ATHEANA explicitly requires the PRA analyst to identify deviations from base-case scenarios normally considered in PRA. The HRA analyst must then assess the vulnerabilities in the operator's knowledge base (Step 5) in concert with complicating factors (Step 7) for the scenarios. For nondeviation base-case scenarios, there are various methods and data that apply. However, the HRA process associated with ATHEANA also involves estimating the error-forcing context for base case deviations and the conditional likelihood of an HFE, given that context. Since HRA data for complex, infrequently observed or considered contexts with potential to challenge operators are often largely absent, ATHEANA provides an expert elicitation process for determining those conditional likelihood estimates. ATHEANA therefore offers a detailed process for uncovering errors of commission and associated error-producing conditions.

The ATHEANA method makes use of HFEs that represent actions or decisions represented in the PRA event tree, and unsafe acts that are modeled in fault trees. Multiple unsafe acts can result in either similar or different HFEs. The process is iterative in nature and has been applied to a number of PRA issues, such as pressurized thermal shock, steam generator tube rupture, and fire analysis. It has also been applied retrospectively to a number of high profile events at U.S. commercial nuclear power plants. The ten-step process is outlined briefly below. It is assumed that the team has already been assembled and trained.

1. *Select the issue*. Define the issue, interpret what needs to be done, and list objectives and human performance concerns.
2. *Define the scope.* Select the initiating event classes and initiating events for analysis, and set priorities on characteristics of event sequences.
3. *Describe the base-case scenario.* For a given initiator, identify the nominal operator and plant behavior. Begin with operationally well-defined scenario(s) and well-understood physics. Understand the trajectories of main parameters, which provide a basis from which to identify and define deviations. Information sources include the Final Safety Analysis Report, parameter plots, thermal-hydraulic analysis, procedures, and operator training requirements.
4. *Define HFEs and unsafe acts*. Review critical functions required to mitigate the event, identifying operator actions and decisions that could degrade critical functions, and produce a list of key actions of concern.
5. *Identify potential vulnerabilities in operator and crew knowledge base*. Identify tendencies and informal rules, and evaluate combinations of information rules and emergency operating procedure for vulnerabilities. Sources of

information include plant procedures, human-machine interface, and training that lead to operator rules, and available emergency operating procedure.

6. *Search for deviation from the base-case scenario*. ATHEANA has advanced a nontraditional discovery process for determining new context(s) for operating events. This is more applicable to event reconstruction or plant-specific prospective analysis. It is less common for development of basic plant models. As part of this process, identify physical deviations from the base case, as well as how initiators can be different. At this stage, the analyst identifies key PSFs and associated error mechanisms, develops system and support dependency matrices, and reviews the potential dependent effects of preinitiator human actions.

   Analysts also identify operator tendency and error types and match various unsafe acts and HFEs. The deviations from the base case, when defined, help to establish the error-forcing context (EFC).

7. *Identify complicating factors and links to various PSFs*. This step includes determining additional physical conditions, hardware failures, configuration problems, unavailability problems, missing or misleading indication, and confusing plant conditions. In addition, this step serves, in general, to expand the definition of error forcing context.

8. *Evaluate recovery factors*. The analyst completes EFC and HFE definitions by considering the opportunities for recovering from initial errors.

9. *Quantify.*

10. *Document.*

4.2.3 Using the SPAR-H Method for a SPAR Base Model

The analyst creating a SPAR base model for a plant uses the SPAR-H method to assign failure probabilities to human actions or diagnosis that correspond to (or are contained by) basic events in the SPAR-H method event trees for the plant.

Given that a human action has been selected for evaluation, the analyst should complete a SPAR-H Human Error Worksheet. The specific information the analyst needs at this point is:

- The SPAR-H method event tree(s) or PRA event tree containing the action, and an understanding of the context in which the action is taking place.
- Whether or not the human action involves diagnosis or is entirely action.
- The available time, as defined in the SPAR-H method, for the human action.
- The level of stress, as defined in the SPAR-H method, affecting the human performers of the action given the context.
- The complexity, as defined in the SPAR-H method, of the human action.
- The relationship of the task to proceeding failed tasks in terms of crew, time, location, and cues—all as defined in the SPAR-H method.
- Additional PSF information corresponding to the PSFs used in application of the method.

The above information should enable the analyst to rate on the first three PSFs (Available Time, Stress and Stressors, and Complexity) on the SPAR-H Human Error Worksheet. The ratings of the last five PSFs (Experience and Training, Procedures, Ergonomics and HMI, Fitness for Duty, and Work Processes) on the SPAR-H Human Error Worksheet should be marked on the nominal rating. This is because these five PSFs are event- or plant-, or even personnel-specific and thus should not be considered at other than a nominal level for the SPAR-H method base model, which is applied across events, plants, and personnel. The opposite is true when using this method in event analysis. In that case, plant operating experience, NRC notices, enforcement actions, root cause corrective efforts, etc., can be used as forms of evidence when assigning a value to these five PSFs. This is explained in detail in the following sections

Typically, dependency is refined as a part of plant-specific analysis. This is because plant specifics may increase or lessen levels of dependency as a result of equipment choice, configuration, or work practices.

4.2.4 Using the SPAR-H Method for SPAR Event Analysis

The starting point for using the SPAR-H method for event analysis is the SPAR base model of the plant to be analyzed. To analyze a selected human action of interest in an event analysis, the analyst first refers to the SPAR-H Human Error Worksheet completed for that human action in support of the SPAR base model for the plant. The analyst then goes through the SPAR-H Human Error Worksheet, point by point, deciding whether the context of the event being analyzed requires that changes be made to the base model analysis. Event analysis is event-specific.

In addition to reviewing equipment availability associated with the event, the analyst must now consider in detail, information about the five PSFs that were automatically rated nominal on the base model's SPAR-H Human Error Worksheet. Additional information that the analyst normally receives at this point is:

- The quality of the experience/training, as defined in the SPAR-H method, of the plant personnel performing the action.
- The quality of the plant procedures, as defined in the SPAR-H method, used in performing the action.
- The quality of the ergonomics, as defined in the SPAR-H method, of the plant controls and displays used in performing the action.
- The fitness for duty, as defined in the SPAR-H method, of the personnel performing the action.
- The quality of the plant and personnel work processes, as defined by the SPAR-H definitions used in the performance of the action.

In summary, to use the SPAR-H method for *operating event analysis*, the analyst examines the changed context of a given human action and decisions during the event and decides whether or not to change any of the eight PSFs or dependency factors on the base model's SPAR-H Human Error Worksheet. A new SPAR-H Human Error Worksheet should be completed if any changes are warranted. Practically speaking, few event reports contain the kind of detail that will allow an analyst to make extensive changes from the base model. However, these reports do provide understanding of a degraded situation that can provide the basis for updating PSFs in the existing model. Much more likely, only a few specific facts will be contained in the event reports, which will provide evidence for differences between the base model and the event.

4.2.5 Sources of Information for Applying the SPAR-H Method to Events

The analyst can probably never have too much information on which to base SPAR-H method ratings. Generally, the problem is just the opposite. Primary sources of event information are licensee event reports, augmented inspection team reports, and the NRC's Resident Inspector. In recent events (such as the degraded condition of the reactor vessel head discovered by Davis Besse), a root cause analysis team report also may be available as a source of PSF information.
Table 4-1 presents some suggestions on where the analyst may acquire the needed information for the eight PSFs and four dependency factors used on the SPAR-H Human Error Worksheet.

The nominal ratings on the SPAR-H Human Error Worksheet are intended for use where ratings actually are "average." For instances where insufficient information is available the analyst now assigns a new category "insufficient information available."

Other sources of information that may be of use to the SPAR-H analyst include:

- Morning report for the event
- Plant procedures
- Other inspection team reports about the plant
- Plant layout diagrams and control room panel diagrams or pictures
- Operator exam results
- Plant training materials
- Event reports from other plants on similar events

Table 4-1. PSF sources of information for SPAR-H.

Needed Information	Source(s)
Available Time	Is nearly always available in both LERs and AIT reports.
Stress/Stressors	Information about stress is more likely found in an AIT report than in an LER, but in either case it will most likely require some inference on the part of the analyst. The analyst is more likely is to find physical and environmental stressors reported directly. Resident Inspector (RI) and Plant Management (PM) sources. Operator examiners are potential information sources.
Complexity	Complexity is generally inferred in LERs and in most AITs. RI and operator examiners are potential information sources.
Experience/Training	AIT report may list for an individual and may comment on shortcomings of training programs. Less likely found in an LER. Operator examiners are another information source.
Procedures	May be able to request procedures used and evaluate then personally. Otherwise, LERs sometimes and AITs almost always contain procedures review.
Ergonomics/HMI	Explicit only in some AIT reports where ergonomics were a concern and a human factors expert was part of the team. However, can often infer, even from an LER. In some instances, the analyst may be able to acquire drawings and procedures indicating location and type of indications used in following procedures. Expect that major influences such as lack of level indication or partial loss of control room annunciation following battery run down will be contained in either event document.
Fitness for duty	Only available in an AIT report; LERs almost never contain this information. RI and PM are other sources.
Work processes	May be able to infer from an LER. Deficiencies are generally detailed explicitly in AIT reports. RI and PM are other sources.
Dependency Factor: Crew	Usually in LERs and AIT reports. RI is another source.
Dependency Factor: Time	Usually in LERs and AIT reports.
Dependency Factor: Location	Generally in LERs and AIT reports.
Dependency Factor: Cues	Much more likely to be referenced in AIT reports than in LERs.

- Inspection recommendations
- Information from walkdowns.

4.2.6 Completing the SPAR-H Human Error Worksheet

Figure 4-1 illustrates the steps in completing the SPAR-H Human Error Worksheet. The text below describes the mechanics of completing the worksheet, as it applies to at-power and LP/SD for base models and events.

1. Determine whether the event applies to at-power or LP/SD. Select the appropriate SPAR-H Worksheet. Both worksheets are identical, except slightly different PSF multipliers are used to reflect different human error probabilities, depending on the mode of operation.
2. Enter header information at the top of the first page of the appropriate SPAR-H Worksheet.

- The name of the plant being rated (e.g., Peach Bottom 2).
- The name of the particular SPAR initiating event being rated (e.g., Loss Of Off-Site Power).
- The basic event code for the basic event being rated.
- The name or initials of the Event Coder.
- The context of the basic event being rated (e.g., the previous basic events in this particular sequence on the SPAR event tree).
- The description of the basic event being rated (e.g., operator fails to throttle high-pressure injection to reduce pressure).

3. Decide whether the basic event human action involves diagnosis and, if so, mark the proper checkbox. Use the "Why?" line below the checkboxes to describe why diagnosis is or is not involved. If diagnosis is not involved, skip Step 4 and proceed with Step 5.

4. Complete Part I, Diagnosis.

   - Rate the eight PSFs for the diagnosis portion of the basic event human action by marking one checkbox for each PSF. Note that when a rating is made, the rater should document the reason for the rating in the block to the right. Each PSF allows the analyst to indicate whether there is insufficient information to rate it. PSFs with insufficient information are given the same multiplier as nominal PSFs.
   - Enter header information from the first page (see Step 2 above) at the top of the second page of the SPAR-H Worksheet.
   - Transfer the multipliers next to the marked checkboxes to the blanks in Section B. Multiply the string of multipliers by 1.0E-2 to calculate the diagnosis failure probability.
   - If there are three or more negative PSF influences, calculate the adjustment factor in Section C. A negative PSF influence is one with a multiplier weighting greater than 1.
   - Record the final diagnosis HEP. This value is equal to the value from Section B or C, depending on whether or not the adjustment factor was applied.

5. Complete Part II, Action. If action is not involved, skip Step 5 and proceed with Step 6.

   - Enter header information from the first page (see Step 2 above) at the top of the third page of the SPAR-H Worksheet.
   - Rate the eight PSFs for the action portion of the basic event human action by marking one checkbox for each PSF. Note that when a rating is made, the rater should document the reason for the rating in the block to the right. Each PSF allows the analyst to indicate if there is insufficient information to rate it. PSFs with insufficient information are given the same multiplier as nominal PSFs.
   - Enter header information from the first page (see Step 1 above) at the top of the fourth page of the SPAR-H Worksheet.
   - Transfer the multipliers next to the marked checkboxes to the blanks in Section B. Multiply the string of multipliers by 1.0E-3 to calculate the diagnosis failure probability.
   - If there are three or more negative PSF influences, calculate the adjustment factor in Section C. A negative PSF influence is one with a multiplier weighting greater than 1.
   - Record the final action HEP. This value is equal to the value from Section B or C, depending on whether or not the adjustment factor was applied.

6. Complete Part III, Calculate the Task Failure Probability Without Formal Dependence.

   - Enter header information from the first page (see Step 2 above) at the top of the fifth page of the SPAR-H Worksheet.

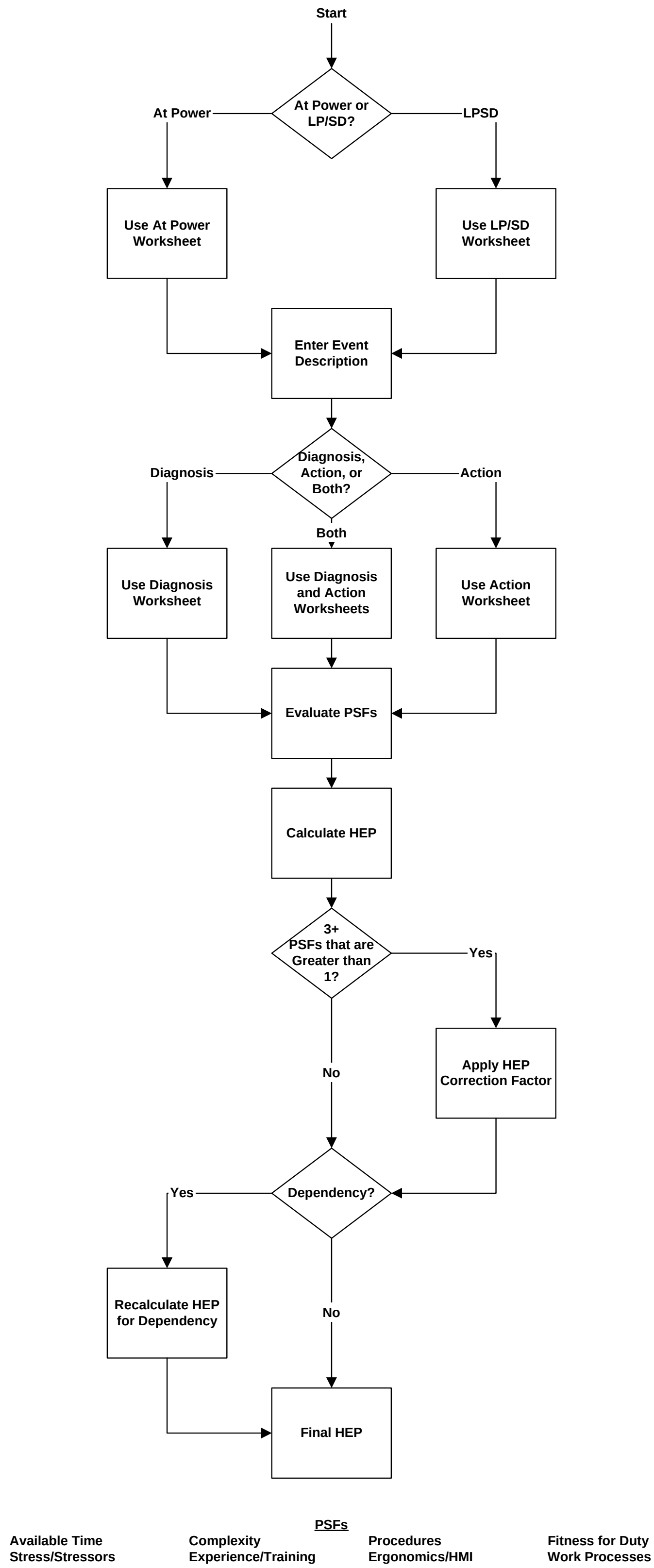

Figure 4-1. Basic flow diagram for completing the SPAR-H worksheets.

- Transfer the diagnosis failure probability from page 1 (if diagnosis is involved) and the action failure probability from page 3 to the blanks in Part III.
- Calculate the task failure probability without formal dependence by adding the diagnosis failure probability to the action failure probability.

7. Complete Part IV, Dependency.
    - Decide whether there is a reason why failure on previous basic events should not be considered in the rating of the present basic event. If, for example, different personnel are involved and have no knowledge of previous tasks, and there are new cues for their tasks, this may make some proportion of their actions independent of these tasks. In other cases, previous tasks may increase or decrease subsequent difficulty, and, thus, some degree of dependency may be present. If there is reason for not considering HRA dependency quantification, then document the reason(s) on the line at the top of Part IV.
    - Decide whether the crew performing the basic event is the same crew that failed the previous basic event in the sequence.
    - Decide whether the basic event is close in time to the previous failed basic event in the sequence. This range extends from a few seconds to a few minutes.
    - Decide whether the basic event takes place in the same location as the previous failed basic event in the sequence.
    - Decide (if not close in time) whether additional cues were available following the previous failed basic event in the sequence. These cues can be additional parameter displays, alarms, or procedures and procedural steps providing guidance to the operator.
    - Follow the choices on the four bullets above through the dependency condition table to arrive at a level of dependency (low to complete). Mark the dependency level in the dependency condition table.
    - 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.
    - Calculate the task failure probability with formal dependence by transferring the task failure probability without formal dependence from Part III into the equation for the proper level of dependence. Clearly indicate which equation was applied.

In addition to the steps above, the analyst may wish to follow additional best-practice guidelines. The following suggestions are designed to improve the quality of the SPAR-H Worksheet:

- When evaluating any procedures that contributed to an event, the specific procedures that were used by personnel should be indicated. This information would typically include the number, section, and subsection for emergency, annunciator, or standard operating procedures.
- If the analyst refers to external sources of information such as event or plant databases, plant personnel, or operations experts, these sources should be noted in the SPAR-H Worksheet.
- When filling out the SPAR-H Worksheet, the analyst should indicate any pertinent information available on indicators and displays. This information should be noted under the Ergonomics/HMI PSF and should be reflected in the selection of the multiplier for the PSF.
- In the absence of plant-specific information, the analyst may wish to assume a crew shift change every 6 to 8 hours for long-duration

LP/SD events. This assumption affects dependency estimations. In SPAR-H, it is generally assumed that the replacement crew has the same number and personnel complement. Any variance from this assumption should be noted in the SPAR-H Worksheet.

It is good practice, upon completion of the SPAR-H Worksheet, to have a second person review the PSF assignments and calculations. The SPAR-H Worksheet includes a place at the bottom of each page for an external reviewer to initial to signify his or her approval.

5. DISCUSSION

5.1 Differences between At-power and LP/SD

A number of significant differences between the human actions, errors, and influences important to at-power operations and those important to LP/SD operations have been identified.

Aspects of the following features are identified as unique and important to LP/SD operations: the kinds of human interaction and events; the classes, modes, and types of human errors (and actions); influences on human performance; and plant conditions and configurations. Unlike at-power operations, all classes of human actions and errors (i.e., initiator, preaccident, and recovery) seem to play a significant role in LP/SD operations and events. In particular, human-initiated events usually are not explicitly treated in at-power PRAs. It is typically assumed that human-initiated events while at at-power can be captured in data collected at the component, system, or plant level and have no detrimental impact on response following the initiator. For LP/SD events, however, human-induced initiators both inside and outside the control room constitute a significant portion of observed errors. In addition, dependencies frequently exist between the activities leading to the initiating event and those required for recovery. These may not be apparent at all times because there exist during LP/SD a large number of potential system configurations and the system response can vary as a function of the current configuration.

Data evaluations indicate that the mistakes versus slips subset of commission dominates the types and modes of human errors, which occur during LP/SD. In addition, mistakes occur both inside and outside the control room during LP/SD. The more direct human-system interactions characteristic of LP/SD operations can result in mistakes, which in turn, lead to unwelcome consequences. In contrast, the human errors explicitly modeled in full-power PRAs are typically errors of omission [e.g., the NRC Generic Letter 88-20 10 CFR 50.54(g)] does not require errors of commission to be modeled in licensee individual plant examinations), and when mistakes are included, only “in control room” errors are typically modeled.

The data collection efforts of this endeavor have resulted in the identification of several important influences on human performance during LP/SD. Through the evaluation of reports, event-based data sources, and interviews, we identified procedures, human engineering and HMI, training, organization factors, and communications as significant contributors to human error and actions. This is consistent with the set of PSFs used in the SPAR-H method. Complexity was not explicitly referenced in these reports, but was thought to be implicitly evident by the members of the analysis team. This was verified by discussions with licensed operators at the INL.

Procedures are important in modeling human errors in full-power PRAs. In LP/SD procedures are also important, however, work packages and work control orders may also figure prominently in plant activities. For at power and LP/SD conditions communications, complexity, and situation awareness should be reviewed as potential influences on human performance. The event-based data evaluations strongly indicate that contributions from multiple influences are common for human actions and errors during LP/SD and at-power events. Also, the available time for event response, frequently an important fact in human performance at at-power, does not appear to be as critical during LP/SD. (Exceptions are likely for events initiated shortly after shutdown when decay heat is high, and for events that can progress unnoticed for extended periods of time).

In the context of nuclear power plant operations, workload and stress are often closely related. Increased workload and stress were often cited in the literature as potential contributors to human error during LP/SD. The presence of a much larger staff, including less-experienced personnel at the plant, as well as the influence of extended work periods, can play significant roles in increasing the workload of operators. However, plant staff interviews indicate that high workload and stress, while potentially significant during LP/SD, did not appear to be at detrimental levels at the plant. It was stated that during an outage, the size of the operations crew is expanded and the shift organization is changed to minimize the impact of the increased workload and to reduce the stress of outage of operations. These measures were cited by the staff as effective in minimizing the impact of outage operations on workload and stress. Therefore, we believe that the addition of personnel may increase organizational load, as opposed to individual load. Increased organizational load can result in unsafe acts, leading to human failure events. Perhaps future research will evaluate staffing and organization factors more directly.

Unlike full-power operations, LP/SD operations are routinely performed under complicated conditions. For example, much greater emphasis is placed on manual control actions. Also, personnel not normally at the plant (e.g., headquarters engineers and contractors) and others not as familiar with the plant's day-to-day work practices and normal operating procedures may be performing tasks that can affect safety. In addition, problems can exist in terms of the operators' ability to observe the state of the plant and the configuration of its equipment.

To their credit, operators generally perform well in the face of continuously changing plant conditions and configurations. Frequent changes in the plant situation have the potential to result in changes in the potential consequences of events because it influences the availability of backup (and, in some cases, front-line) equipment in event responses. Additionally, the changing plant environment during LP/SD calls attention to importance of communications in supporting outage activities safely and to appropriately respond to LP/SD events. Also, equipment operated manually on a routine basis during LP/SD operations and the response to LP/SD events are typically achieved through manual human actions rather than automatic equipment response.

These differences from at-power operations help create a situation in LP/SD where certain types of errors may be more likely and their consequences less observable. However, a significant mitigating factor is that, after the first few days of an outage, the time required for fuel to become uncovered following loss of cooling, for example, is sufficiently extended so that delays in recovering from errors may have less impact on risk.

Despite these differences in uncertainty regarding day-to-day operations and in personnel availability, the SPAR-H method has kept the same PSF grouping used for full-power operations. Many influences, such as shift work effects, time of day, and other personnel factors, are captured under the fitness-for-duty PSF. Reliance upon work orders as opposed to more formal procedures is captured under work processes. Until progress in determining the key aspects of work process factors such as safety culture upon risk can be placed in a qualitative framework, they are best handled as PSFs whose effects are multiplied against base failure rates.

5.2 Compliance with ASME Standard on PRA

While the current version of the SPAR-H method was being completed, the standard for the conduct of PRA (ASME RA-S-2002) was released. The following indicates areas where the SPAR-H method is in compliance and where it is not, and if not, why. In general, there are some differences between the SPAR-H approach and the ASME standard. These are as follows.

5.2.1 Organization

ASME PRA is organized according to nine PRA elements, including initiating events (IEs), accident sequence analysis, success criteria, and systems analysis. SPAR-H begins with the assumption that PRA has provided detail regarding IEs to the HRA analyst. The same is assumed for information regarding accident sequence analysis, success criteria, and systems analysis. The HRA analyst is expected to interact with the rest of the PRA team.

5.2.2 Documentation

ASME PRA provides guidance regarding the control of PRA documentation. SPAR-H does not address this issue. We believe that individual entities have the responsibility to develop and maintain their own configuration control over PRA/HRA documentation. The only requirement for documentation control cited in this report refers to the SPAR-H requirement that analysts and reviewer sign each HRA worksheet and that they document the assumptions behind each PSF assignment. Otherwise, only the documentation that is required in a credible HRA should apply. This would include maintenance of an engineering design file and copies of relevant plant procedures, databases, task analysis results, or any other pertinent information used by the HRA analyst to support the HRA. Defining these requirements further is not within the scope of this report.

5.2.3 Expert Judgment

ASME reviews the role of expert judgment methods and presents requirements. SPAR-H attempts to provide a simple, consistent, and easy-to-use method that reduces expert judgment as much as possible. We acknowledge that there are potentially some domains such as extreme events where the context is so novel or strongly negative that the applicability of the base failure rates in SPAR-H and the range of effect for PSFs as well as the applicability of these PSFs should be reviewed.

5.2.4 Activity Types

ASME differentiates among preinitiator HRA, postinitiating event activities, and special cases such as restoration, and provides definitions for logic model elements. SPAR-H assumes that the underlying model for human performance is the same for pre- versus postinitiator actions and diagnoses and that any differences can be accounted for by the proper assignment of PSFs.

5.2.5 Work Processes

ASME requirements call attention to identifying work processes that could introduce mechanisms that simultaneously affect equipment in different trains of either redundant or diverse systems. SPAR-H recognizes this as a significant failure mode but does not present requirements regarding the search for common-cause mechanisms. SPAR-H suggests that if analysts consult approaches such as those in SHARP1 or ATHEANA, that they be responsive to the ASME common-cause requirements.

5.2.6 Probability Assignment

ASME lists two other important high-level requirements: to use a systematic process to estimate human error probabilities (THERP and ASEP are given as examples, p. 50), and to use mean values when providing HEP estimates. As part of the development process, SPAR-H was reviewed against THERP and ASEP for nominal values for diagnosis and action, and reviewed again when determining the range of PSF influences. SPAR-H provides mean values that can be used in conjunction with a constrained non-informative before producing upper and lower bound estimates for the HEP.

The ASME standard suggests (p. 48) that assessment of the probabilities of the postinitiator HFEs be performed using a well-defined and self-consistent process. This process must address the plant-specific and scenario-specific influences on human performance and between human failure events within the same sequence. The SPAR-H method process is simple, internally consistent, and relatively easy to apply. Two base rates are proposed: one for diagnosis and one for action; and the same eight PSFs are required for evaluation of every HEP.

The ASME standard suggests that the analyst check the reasonableness of HEPs in light of the plant's operating history, procedures, operational practices, and experience.

The ASME standard requires that some assessment of the uncertainty in HEPs be conducted. The SPAR-H method provides an approach by which uncertainty associated with HEPs can be determined.

5.2.7 PSF Inclusion

ASME notes a number of performance influences that the analyst should account for. These influences correspond to the PSFs in SPAR-H. These include procedures, including specification of the procedural guidance (EOP and AOP); ergonomic considerations, including cues; availability of instrumentation; adequacy of special tools and accessibility; complexity of the required response; quality of training and experience; the time available and time required to respond; and “some measure of scenario induced stress” (see p. 53).

Finally, ASME is specific regarding those factors that must be present on a plant-specific basis in order to give credit for operator recovery actions. SPAR-H is nonspecific on this issue, and analysts should consider the guidance of ASME.

5.2.8 Dependency and Procedures

As is fitting with a standards approach, ASME does not prescribe a unique approach to dependency calculation or uncertainty analysis. SPAR-H prescribes an approach to dependency determination and quantification. Suggestions for uncertainty assessment are provided as well.

Dependency assignment in SPAR-H is adapted from THERP. The consideration of plant and scenario-specific factors is evidenced in the identification and characterization of errors that are modeled and in the analyst shaping factor level assignments. Defaults for individual PSFs are for situations where no influence by the PSF is expected or where insufficient information regarding the PSF exists. Assessment of task dependency is straightforward and allows for consideration of elements of context, such as the crew depending on the same cues originating from either inadequate or adequate procedures and or instrumentation. Quantification follows THERP guidelines.

5.2.9 Procedures Review and Documentation

ASME RA-S-2002, HLR-HR-E Section 4.5.5.1 requires analysts to perform a systematic review of relevant procedures. The review of procedure information, coupled with walkdowns, interviews, and review of event databases, is suggested as part of the review of SPAR-H basics covered in Section 1 of this report. However, beginning with first-generation HRA, analysts have reviewed procedures in support of the HRA process. SPAR-H assumes that any HRA analyst will do the same. The range of procedures that can be subject to review can include normal operating procedures, abnormal operating procedures, emergency operating procedures, and test, calibration, and surveillance procedures.

The ASME standard specifically requires that the documentation provided by the analyst describe the analysis processes used and details of underlying assumptions made. The SPAR-H method requires the analyst to document on the HRA worksheets assumptions made when assigning PSF values. We believe that analysts should always state in the body of the PRA/HRA key assumptions regarding human performance, availability of equipment and indications, procedures, unusual aspects of the event in terms of plant configuration or conditions, unusual or unexpected system response, and assumptions regarding the time available and time required for operators and crew to respond.

5.2.10 Supporting Requirements for HRA

Unlike the ASME standard, SPAR-H does not provide guidance on how to develop PRA-specific screening approaches. We believe it best that the analyst apply the worksheets completely for any application including screening. The analysis should be consistent and scaled to the same level of decomposition to allow for proper quantification. Likewise, the categorization scheme identified in the ASME for capability categories I, II, and III is not called out specifically in SPAR-H. Rather, those activities and insights are used to support human response logic model (i.e., fault tree) development or as part of the PSF evaluation process. For example, independent checking by a second operator can be represented in fault tree logic model structure or taken into account when evaluating the quality of work processes PSF. The appropriateness of the assignment is a function of the application and the scenario.

5.2.11 Recovery

The ASME standard specifies a number of considerations for recovery, self-recovery, or recovery by other crews, and lists a number of conditions. The SPAR-H method is much more brief and only advises that recovery be considered in the logic structure of fault tree models used by analysts, and refers them to SHARP or the ASME standard for guidance. The SPAR-H method does not go into specifics regarding credit for use of written checkoff lists, work shift, or daily checks of components, etc.

The ASME standard specifically directs analysts to define a set of HFEs as unavailability's of functions, systems, or components at the appropriate level of detail. The SPAR-H method calls for the definition of HFEs in the same language but recommends fault tree and event tree structure congruent with the concepts of HFE and context expressed in ATHEANA and other second-generation methods.

5.2.12 Timing

The ASME standard specifies the analyst determine the specific timing of the accident sequence, relevant cues and time window for completion. The SPAR-H method assigns weighting factors based on available time windows. Timing and appearance of cues are noted in the ergonomics/HMI PSF. PSF details should be noted in the comments column of the worksheets. Although not required by SPAR-H, the analyst may wish to develop functional timelines for events to aid them in characterizing human-system performance and discrete changes in PSFs.

The ASME standard specifies that the definition of HFEs should coincide with accident-specific procedural guidance. The SPAR-H method leaves the determination of HFEs up to the analysis team.

5.2.13 Screening

For screening analysis, the ASME standard suggests use of conservative estimates or detailed analysis of HEP estimation in dominant accident sequences. The SPAR-H method is compatible with this suggestion, although the SPAR-H method attempts to be more realistic than a pure screening by offering a relatively large dynamic range and mixture of PSFs for consideration in the quantification process.

Earlier versions of the ASME standard specified values for screening. That feature has been removed from the current standard. Many of the values prescribed were not consistent with approaches used in shutdown HRA, such as that included in NUREG/CR-6144 (1995). It also called for relatively high HEPs, on the order of 0.50, for postinitiator screening values. This feature was also removed. For a detailed screening technique, such as the SPAR-H method, use of such coarse HEP values bypasses the utility of the current approach.

5.2.14 Task Characteristics

Task characteristics to consider that are spelled out in the ASME standard and that constitute part of the analysis process undertaken by the SPAR-H analyst include:

- Number of subtasks
- Complexity and difficulty of required actions
- Task performed inside or outside of the control room
- Addressing both diagnosis and execution for each postinitiator
- Diagnosis—detecting, evaluating, and deciding response
- Execution—performing activities indicated by diagnosis.

5.3 NASA Guidelines

The SPAR-H method is also consistent with a number of the elements outlined in the NASA PRA Procedures Guidelines (Stamatelatos and Dezfuli, 2002). The NASA guide reviews different human interaction (HI) classification strategies in contemporary HRA. The system most widely used employs the nomenclature HI-A,-B and -C, which correspond to pre-initiating event interactions, initiating event-related interactions, and post-initiating event actions, respectively.

The SPAR-H method is capable of providing estimates for HI-A and HI-C, and suggests that frequencies for initiating events be used from operations or industry data where possible. The NASA guide and the SPAR-H method break down HI-C (postinitiator responses) into *cognitive responses* and *action responses*. This bears a direct similarity to the overarching diagnosis/action task taxonomy used by the SPAR-H method.

The NASA guide distinguishes between skill-, rule-, and knowledge-based (SRK) behavior (Rasmussen 1979) and omission- and commission-based errors. These are not inconsistent with the SPAR-H method. SPAR analysts should take the knowledge domains used by operators in conjunction with their training into account when identifying errors for consideration in their analysis.

For approaches focusing on errors of commission, see Pyy (2000), Bieder et al. (1999), or Forester et al. (NUREG-1624 2000). The SPAR-H method uses a blended rate for errors of omission and commission. This is thought to be sufficient for model building and for most other SPAR model applications. Just as in the case of SRK, use of omission and commission is not explicitly called out in our approach. However, it should be present as part of the mindset of the HRA analyst as s/he considers possible errors.

Consistent with most HRA approaches, the NASA guide suggests that task analysis be used in support of HRA. This is part of the SPAR-H method and many other HRA approaches beginning with THERP.

In terms of similarities, more remarkable perhaps is the degree to which PSFs suggested by the NASA guide and those included in the SPAR-H method overlap. For example, typical PSFs suggested by both the NASA guide and the SPAR-H method for consideration include procedures, quality of human-machine interface (ergonomics/HMI in SPAR-H nomenclature); training and practice (training and experience in the SPAR-H method); task complexity (complexity in the SPAR-H method); stress level (stress in the SPAR-H method); time available or time urgency (available time and stress in the SPAR-H method); environmental conditions (part of ergonomics/HMI in the SPAR-H method); communication (not directly covered in the SPAR-H method); and previous actions (covered by dependency in the SPAR-H method).

The separation of environmental conditions from ergonomics in the NASA guide reflects the high degree of consideration given to the effects of microgravity on task performance. Also, communication between mission specialists and ground control operations or among crew, many of whom might be using English as a second language, emphasizes the importance of communication for that domain. The authors of the NASA guide also note that organizational and management factors can be important but are not usually explicitly modeled in HRA. However, they can be inferred by their impact on procedures, interface, training, and other variables.

The SPAR-H method considers a subset of organizational factors and work processes, in explicit fashion, for the impact on human performance and allows for quantification based on this information. The SPAR-H method also directly calls out fitness for duty as an influential variable regarding human response. Aspects of fitness for duty are more implicitly dealt with in the NASA guide. The NASA guide also reviews approaches to screening analysis versus detailed analysis. The SPAR-H method is already a simplified approach, but could be used to assist in either qualitative or quantitative screening analysis. Because of the mandatory consideration of PSFs within the SPAR-H method, the approach it uses in support of the screening analysis process would have to be considered detailed HRA screening analysis. The NASA guide also refers the reader to the NUREG/CR-1278 (1983) quantification model and five levels of dependency. The SPAR-H method uses a similar approach to the suggested quantification from THERP but provides supplemental qualitative information needed to assign the level of dependency before quantification. In terms of uncertainty, the reasons for use of the beta distribution are summarized above in this report.

5.4 General Discussion

The SPAR-H method has been developed to be straightforward, easy to apply, and based on both a human information-processing model of human performance and results from human performance studies. This simple HRA approach contains a number of enhancements, including calibration of its base failure rates and range of PSFs influence against other HRA methods. This version of the SPAR-H method also contains a revised approach to uncertainty analysis, employing a beta distribution that obviates problems experienced in earlier versions when applying error factor approaches. The SPAR-H method also provides a adjustment factor to reduce the likelihood of double correcting the influence of PSFs due to their relationship to other PSFs.

The SPAR-H method has been refined as a result of experience gained during its use in the development of over 70 SPAR plant models for the NRC; in limited HRA applications for dry cask, spent fuel storage; in implementation of risk-informed plant inspection notebooks; and through third-party application to other domains, such as aerospace. Although there have not been formal trial applications by teams of independent analysts, the method has been revised based on the experience of teams in applying the method over the past ten years, as described above. The method does not differentiate between active and latent failures; their identification and modeling is the decision of the analyst. It is thought that the same PSFs and base failure rates are applicable to either type of error. The base error rates contained in the worksheets for actions and diagnosis include omission and commission types of errors. The tendency for an omission or commission to be more important in contributing to an individual human failure event can be modeled by the analyst using subtask level of decomposition in building supporting fault trees.

Although recognition that work processes are important is not new in HRA, the explicit incorporation of work processes is relatively new. In instances where the effects of particular PSFs, such as work processes are difficult to determine, the range of effect used in the SPAR-H method reflects the treatment of the work process PSF in other HRA methods. For example, the work processes' range of effect in the SPAR-H method is enveloped by identification of a range of effect for work process PSF in two methods, CREAM (Hollnagel 1998) and HEART (Williams 1988). The range in the SPAR-H method is within the bounds suggested by these methods.

Other recent efforts related to work process analysis include that of Weil and Apostolakis (2001). Dynamic approaches to work process analysis at nuclear facilities is presented in Shukri and Mosleh (1998). They treat crew performance factors, including aspects influenced by work processes, in conjunction with dynamic plant response determined by plant thermal-hydraulic calculations. See also Chang and Mosleh (1998) for an overall description of the integration of RELAP-5 thermo-hydraulic computer code with the IDA crew performance model.

It may take time to reach consensus as a community regarding how to model and quantify the effect of work processes on performance, because work processes have an indirect and pervasive influence on performance. The extent to which work process elements, such as poor configuration control, work order discrepancies, the amount of re-work, infractions, risk worth of corrective action backlog, and more objective elements, can be measured will help us to formulate a manner for including work processes in PRA through HRA.

Traditionally, accounting for the influence of multiple shaping factors with multiple levels of influence without imposing a high degree of expert consensus judgment on the HRA process has proven difficult. The SPAR-H method attempts to make the assignment of human error probability more reliable by presenting analysts with a consistent set of PSFs for evaluation. The HRA search process for determining unsafe acts, given a particular context, still remains a challenging task for the PRA/HRA analyst, but this is the information that is brought to the SPAR-H method for quantification. The need to provide sound qualitative assessments of PSFs is amplified as the SPAR-H method applications move from basic plant PRA model development to event analysis and HRA analysis for specific issues.

HRA has become a central topic to PRA, in part due to the compelling notion regarding the importance of psychology, action, and mental activities in everyday life. In the nearly 30 years since WASH 1400 was issued (Rasmussen 1975), appreciation of the importance of human error in nuclear power plants has increased considerably. Starting with a crude diagnosis model based on time, HRA practitioners now look more systematically at complexity, context, situation awareness, and complicating conditions as factors in addition to time that may influence crew diagnosis and response. Theory and model building have continued with general recognition of the importance of special issues such as errors of commission, cognitive control, and work

Table 5-1 SPAR-H method assessment.

HRA Method Criterion	SPAR-H Method Rating	Explanation
The method should be objective and internally consistent.	Moderate	Experience with use of the SPAR-H method suggests training time is minimal, and the level at which analysis is conducted is consistent throughout.
The method should produce consistent results.	High	The use of defined levels of influence, base rates, and worksheets serves to produce consistent results, given the same input.
It should possess temporal halves reliability.	Undetermined	An existing analysis would have to be revisited at a later date and analysts would have to evaluate the same HEPs, after which the extent to which the first and second evaluations matched would have to be determined.
It should possess face and construct validity.	High	The method is consistent with human behavior modeling and appears to capture the majority of elements considered in HRA. The relationship to human performance at NPPs is obvious.
It should be documented and field-tested.	Moderate	The method has been field-tested for some years and has been in use as part of SPAR model development, but the documentation is only now becoming widely available.
It should produce estimates consistent with the practice of HRA and with operating experience.	High	The rates and range of influence have been calibrated against existing methods and offers the analyst the range of PSFs that would make application findings consistent with operating experience
It should be applicable across domains.	Moderate	The method has been extended to ground operations for aerospace with some degree of success; application to additional domains is needed to further establish robustness of the method.
It should be subject to peer review.	Limited	The method is not yet widely distributed nor reviewed.
Output from the method should be compatible with existing or emerging PRA logic structures.	High	The method was designed to produce output suitable for use in PRA event or fault tree logic structures.
The method should be easy to apply.	High	The method employs predefined fields, including PSFs, basic error rates, and method for dependency assignment and quantification. Determining the final HEP is relatively easy.
The method should be easy to obtain.	Moderate	With publication in NUREG format and availability on the Web and in conference proceedings, information about the method is easily obtained.

processes. In the last 10 years, the importance of errors of cognition has been recognized. It is likely that some time in the future there will be a uniform treatment of uncertainty in HRA.

Human interaction with advanced technologies is a frontier for which data are needed. Task sharing between human and intelligent systems in robotic environments is now becoming commonplace. Much of it proceeds because the technology has become available. A time is envisioned in the future when this technology will be introduced into the control room or perhaps balance-of-plant activities. For example, consider self-maintaining, self regulating systems. In fact, the importance of advancing or extending the experimental techniques now available to collect HRA data cannot be overemphasized. More is probably known about the factors that cause crews to fail than to succeed. For example, complexity is acknowledged as an influence on performance. Complexity may impact the searches that crews conduct to support hypothesis generation. Does it cause a narrowing of the search space or just a diminished capacity to perform? If so, how? And if so, are serial searches or parallel searches more susceptible to disruption? How can the impact of this phenomenon be reduced? One approach is to simplify the work environment to reduce workload. But if everything except emergency situations is simplified, is the workload reduced to the point that we are now more, rather than less, vulnerable? How are skills and alertness maintained so that they do not have a negative impact on safety-significant situations? What role should designing multi-modal systems (vision, audition, touch) play in building cognitive support systems for future generation plants or backfits to existing plants?

It is apparent that HRA data collection must be sponsored to meet the needs of the future while applying the resources available to risk informing current decision-making.

Once the answers to some of these issues are found, the character of HRA will be further improved.

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Appendix A

HRA Worksheets for At-Power

HRA Worksheets for At-Power

SPAR HUMAN ERROR WORKSHEET

Plant:__________Initiating Event:________Basic Event :_____________ Event Coder:____________

Basic Event Context:____

Basic Event Description:____

Does this task contain a significant amount of diagnosis activity? YES ☐ (start with Part I–Diagnosis) NO ☐ (skip Part I – Diagnosis; start with Part II – Action) Why?____

PART I. EVALUATE EACH PSF FOR DIAGNOSIS

A. Evaluate PSFs for the Diagnosis Portion of the Task, If Any.

PSFs	PSF Levels	Multiplier for Diagnosis	Please note specific reasons for PSF level selection in this column.
Available Time	Inadequate time	P(failure) = 1.0 ☐	
	Barely adequate time (≈2/3 x nominal)	10 ☐	
	Nominal time	1 ☐	
	Extra time (between 1 and 2 x nominal and > than 30 min)	0.1 ☐	
	Expansive time (> 2 x nominal and > 30 min)	0.01 ☐	
	Insufficient information	1 ☐	
Stress/ Stressors	Extreme	5 ☐	
	High	2 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Complexity	Highly complex	5 ☐	
	Moderately complex	2 ☐	
	Nominal	1 ☐	
	Obvious diagnosis	0.1 ☐	
	Insufficient Information	1 ☐	
Experience/ Training	Low	10 ☐	
	Nominal	1 ☐	
	High	0.5 ☐	
	Insufficient Information	1 ☐	
Procedures	Not available	50 ☐	
	Incomplete	20 ☐	
	Available, but poor	5 ☐	
	Nominal	1 ☐	
	Diagnostic/symptom oriented	0.5 ☐	
	Insufficient Information	1 ☐	
Ergonomics/ HMI	Missing/Misleading	50 ☐	
	Poor	10 ☐	
	Nominal	1 ☐	
	Good	0.5 ☐	
	Insufficient Information	1 ☐	
Fitness for Duty	Unfit	P(failure) = 1.0 ☐	
	Degraded Fitness	5 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Work Processes	Poor	2 ☐	
	Nominal	1 ☐	
	Good	0.8 ☐	
	Insufficient Information	1 ☐	

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Plant:_________Initiating Event:_______Basic Event :____________ Event Coder:___________

Basic Event Context:____

Basic Event Description:____

B. Calculate the Diagnosis Failure Probability.

(1) If all PSF ratings are nominal, then the Diagnosis Failure Probability = 1.0E-2
(2) Otherwise, the Diagnosis Failure Probability is: 1.0E-2 x Time x Stress or Stressors x Complexity x Experience or Training x Procedures x Ergonomics or HMI x Fitness for Duty x Processes

Diagnosis: 1.0E-2x ____ x ____ x ____ x ____ x ____ x ____ x ____ x ____ = [ ]

C. Calculate the Adjustment Factor <u>IF</u> Negative Multiple (≥3) PSFs are Present.

When 3 or more negative PSF influences are present, in lieu of the equation above, you must compute a composite PSF score used in conjunction with the adjustment factor. Negative PSFs are present anytime a multiplier greater than 1 is selected. The Nominal HEP (NHEP) is 1.0E-2 for Diagnosis. The composite PSF score is computed by multiplying all the assigned PSF values. Then the adjustment factor below is applied to compute the HEP:

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

Diagnosis HEP with Adjustment Factor = [ ]

D. Record Final Diagnosis HEP.

If no adjustment factor was applied, record the value from Part B as your final diagnosis HEP. If an adjustment factor was applied, record the value from Part C.

Final Diagnosis HEP = [ ]

Reviewer: ___________

Plant:_________Initiating Event:_______Basic Event :____________ Event Coder:___________

Basic Event Context:____

Basic Event Description:____

Part II. EVALUATE EACH PSF FOR ACTION

A. Evaluate PSFs for the Action Portion of the Task, If Any.

PSFs	PSF Levels	Multiplier for Action	Please note specific reasons for PSF level selection in this column.
Available Time	Inadequate time	P(failure) = 1.0 ☐	
	Time available is ≈ the time required	10 ☐	
	Nominal time	1 ☐	
	Time available ≥ 5x the time required	0.1 ☐	
	Time available is ≥ 50x the time required	0.01 ☐	
	Insufficient Information	1 ☐	
Stress/ Stressors	Extreme	5 ☐	
	High	2 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Complexity	Highly complex	5 ☐	
	Moderately complex	2 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Experience/ Training	Low	3 ☐	
	Nominal	1 ☐	
	High	0.5 ☐	
	Insufficient Information	1 ☐	
Procedures	Not available	50 ☐	
	Incomplete	20 ☐	
	Available, but poor	5 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Ergonomics/ HMI	Missing/Misleading	50 ☐	
	Poor	10 ☐	
	Nominal	1 ☐	
	Good	0.5 ☐	
	Insufficient Information	1 ☐	
Fitness for Duty	Unfit	P(failure) = 1.0 ☐	
	Degraded Fitness	5 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Work Processes	Poor	5 ☐	
	Nominal	1 ☐	
	Good	0.5 ☐	
	Insufficient Information	1 ☐	

Reviewer: ____________

Plant:_________Initiating Event:_______Basic Event :____________ Event Coder:___________

Basic Event Context:____

Basic Event Description:____

B. Calculate the Action Failure Probability.

(1) If all PSF ratings are nominal, then the Action Failure Probability = 1.0E-3
(2) Otherwise, the Action Failure Probability is: 1.0E-3 x Time x Stress or Stressors x Complexity x Experience or Training x Procedures x Ergonomics or HMI x Fitness for Duty x Processes

Action: 1.0E-3x ____ x ____ x ____ x ____ x ____ x ____ x ____ x ____ = [ ]

C. Calculate the Adjustment Factor <u>IF</u> Negative Multiple (≥3) PSFs are Present.

When 3 or more negative PSF influences are present, in lieu of the equation above, you must compute a composite PSF score used in conjunction with the adjustment factor. Negative PSFs are present anytime a multiplier greater than 1 is selected. The Nominal HEP (NHEP) is 1.0E-3 for Action. The composite PSF score is computed by multiplying all the assigned PSF values. Then the adjustment factor below is applied to compute the HEP:

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

Action HEP with Adjustment Factor = [ ]

D. Record Final Action HEP.

If no adjustment factor was applied, record the value from Part B as your final action HEP. If an adjustment factor was applied, record the value from Part C.

Final Action HEP = [ ]

Reviewer: ___________

Plant:_________Initiating Event:_______Basic Event :___________ Event Coder:___________

Basic Event Context:____

Basic Event Description:____

PART III. CALCULATE TASK FAILURE PROBABILITY WITHOUT FORMAL DEPENDENCE ($P_{W/OD}$)

Calculate the Task Failure Probability Without Formal Dependence ($P_{w/od}$) by adding the Diagnosis Failure Probability from Part I and the Action Failure Probability from Part II. In instances where an action is required without a diagnosis and there is no dependency, then this step is omitted.

$P_{w/od}$ = Diagnosis HEP _________ + Action HEP _________ = [ ]

Part IV. DEPENDENCY

For all tasks, except the first task in the sequence, use the table and formulae below to calculate the Task Failure Probability With Formal Dependence ($P_{w/d}$).

If there is a reason why failure on previous tasks should not be considered, such as it is impossible to take the current action unless the previous action has been properly performed, explain here: _________________________

Dependency Condition Table

Condition Number	Crew (same or different)	Time (close in time or not close in time)	Location (same or different)	Cues (additional or no additional)	Dependency	Number of Human Action Failures Rule ☐ - Not Applicable. Why?_________________
1	s	c	s	na	complete	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.**
2				a	complete	
3			d	na	high	
4				a	high	
5		nc	s	na	high	
6				a	moderate	
7			d	na	moderate	
8				a	low	
9	d	c	s	na	moderate	
10				a	moderate	
11			d	na	moderate	
12				a	moderate	
13		nc	s	na	low	
14				a	low	
15			d	na	low	
16				a	low	
17					zero	

Using $P_{w/od}$ = Probability of Task Failure Without Formal Dependence (calculated in Part III):

For Complete Dependence the probability of failure is 1.
For High Dependence the probability of failure is $(1+ P_{w/od})/2$
For Moderate Dependence the probability of failure is $(1+6 \times P_{w/od})/7$
For Low Dependence the probability of failure is $(1+19 \times P_{w/od})/20$
For Zero Dependence the probability of failure is $P_{w/od}$

Calculate $P_{w/d}$ using the appropriate values:

$P_{w/d}$ = (1 + (_______ * _______))/ _______ = [ ]

Reviewer: ____________

Appendix B

HRA Worksheets for LP/SD

HRA Worksheets for LP/SD

SPAR Human Error Worksheet

Plant:_________Initiating Event:_______Basic Event :____________ Event Coder:___________

Basic Event Context:____

Basic Event Description:____

Does this task contain a significant amount of diagnosis activity? YES ☐ (start with Part I–Diagnosis) NO ☐ (skip Part I – Diagnosis; start with Part II – Action) Why?______________________________________

PART I. EVALUATE EACH PSF FOR DIAGNOSIS

A. Evaluate PSFs for the Diagnosis Portion of the Task.

PSFs	PSF Levels	Multiplier for Diagnosis	Please note specific reasons for PSF level selection in this column.
Available Time	Inadequate time	P(failure) = 1.0 ☐	
	Barely adequate time (≈ 2/3 x nominal)	10 ☐	
	Nominal time	1 ☐	
	Extra time (between 1and 2 x nominal and > 30 min)	0.1 ☐	
	Expansive time > 2 x nominal & > 30 min	0.1 to 0.01 ☐	
	Insufficient Information	1 ☐	
Stress/ Stressors	Extreme	5 ☐	
	High	2 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Complexity	Highly complex	5 ☐	
	Moderately complex	2 ☐	
	Nominal	1 ☐	
	Obvious diagnosis	0.1 ☐	
	Insufficient Information	1 ☐	
Experience/ Training	Low	10 ☐	
	Nominal	1 ☐	
	High	0.5 ☐	
	Insufficient Information	1 ☐	
Procedures	Not available	50 ☐	
	Incomplete	20 ☐	
	Available, but poor	5 ☐	
	Nominal	1 ☐	
	Diagnostic/symptom oriented	0.5 ☐	
	Insufficient Information	1 ☐	
Ergonomics/ HMI	Missing/Misleading	50 ☐	
	Poor	10 ☐	
	Nominal	1 ☐	
	Good	0.5 ☐	
	Insufficient Information	1 ☐	
Fitness for Duty	Unfit	P(failure) = 1.0 ☐	
	Degraded Fitness	5 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Work Processes	Poor	2 ☐	
	Nominal	1 ☐	
	Good	0.8 ☐	
	Insufficient Information	1 ☐	

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Plant:_________Initiating Event:_______Basic Event :____________ Event Coder:___________

Basic Event Context:____

Basic Event Description:____

B. Calculate the Diagnosis Failure Probability.

(1) If all PSF ratings are nominal, then the Diagnosis Failure Probability = 1.0E-2
(2) Otherwise, the Diagnosis Failure Probability is: 1.0E-2 x Time x Stress or Stressors x Complexity x Experience or Training x Procedures x Ergonomics or HMI x Fitness for Duty x Processes

Diagnosis: 1.0E-2x ____ x ____ x ____ x ____ x ____ x ____ x ____ x ____ = [ ]

C. Calculate the Adjustment Factor <u>IF</u> Negative Multiple (≥3) PSFs are Present.

When 3 or more negative PSF influences are present, in lieu of the equation above, you must compute a composite PSF score used in conjunction with the adjustment factor. Negative PSFs are present anytime a multiplier greater than 1 is selected. The Nominal HEP (NHEP) is 1.0E-2 for Diagnosis. The composite PSF score is computed by multiplying all the assigned PSF values. Then the adjustment factor below is applied to compute the HEP:

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

Diagnosis HEP with Adjustment Factor = [ ]

D. Record Final Diagnosis HEP.

If no adjustment factor was applied, record the value from Part B as your final diagnosis HEP. If an adjustment factor was applied, record the value from Part C.

Final Diagnosis HEP = [ ]

Reviewer: ____________

Plant:_________Initiating Event:_______Basic Event :____________ Event Coder:___________

Basic Event Context:____

Basic Event Description:____

Part II. EVALUATE EACH PSF FOR ACTION

A. Evaluate PSFs for the Action Portion of the Task, If Any.

PSFs	PSF Levels	Multiplier for Action	Please note specific reasons for PSF level selection in this column.
Available Time	Inadequate time	P(failure) = 1.0 ☐	
	Time available is ≈ the time required	10 ☐	
	Nominal time	1 ☐	
	Time available ≥ 5x the time required	0.1 ☐	
	Time available is ≥ 50x the time required	0.01 ☐	
	Insufficient Information	1 ☐	
Stress/ Stressors	Extreme	5 ☐	
	High	2 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Complexity	Highly complex	5 ☐	
	Moderately complex	2 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Experience/ Training	Low	3 ☐	
	Nominal	1 ☐	
	High	0.5 ☐	
	Insufficient Information	1 ☐	
Procedures	Not available	50 ☐	
	Incomplete	20 ☐	
	Available, but poor	5 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Ergonomics/ HMI	Missing/Misleading	50 ☐	
	Poor	10 ☐	
	Nominal	1 ☐	
	Good	0.5 ☐	
	Insufficient Information	1 ☐	
Fitness for Duty	Unfit	P(failure) = 1.0 ☐	
	Degraded Fitness	5 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Work Processes	Poor	5 ☐	
	Nominal	1 ☐	
	Good	0.5 ☐	
	Insufficient Information	1 ☐	

Reviewer: ___________

B. Calculate the Action Failure Probability.

(1) If all PSF ratings are nominal, then the Action Failure Probability = 1.0E-3
(2) Otherwise, the Action Failure Probability is: 1.0E-3 x Time x Stress or Stressors x Complexity x Experience or Training x Procedures x Ergonomics or HMI x Fitness for Duty x Processes

Action: 1.0E-3x ____ x ____ x ____ x ____ x ____ x ____ x ____ x ____ = [ ]

C. Calculate the Adjustment Factor <u>IF</u> Negative Multiple (≥3) PSFs are Present.

When 3 or more negative PSF influences are present, in lieu of the equation above, you must compute a composite PSF score used in conjunction with the adjustment factor. Negative PSFs are present anytime a multiplier greater than 1 is selected. The Nominal HEP (NHEP) is 1.0E-3 for Action. The composite PSF score is computed by multiplying all the assigned PSF values. Then the adjustment factor below is applied to compute the HEP:

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

Action HEP with Adjustment Factor = [ ]

D. Record Final Action HEP.

If no adjustment factor was applied, record the value from Part B as your final action HEP. If an adjustment factor was applied, record the value from Part C.

Final Action HEP = [ ]

Basic Event Context:____

Basic Event Description:____

PART III. CALCULATE TASK FAILURE PROBABILITY WITHOUT FORMAL DEPENDENCE ($P_{W/OD}$)

Calculate the Task Failure Probability Without Formal Dependence ($P_{w/od}$) by adding the Diagnosis Failure Probability from Part I and the Action Failure Probability from Part II. In instances where an action is required without a diagnosis and there is no dependency, then this step is omitted.

$P_{w/od}$ = Diagnosis HEP _________ + Action HEP _________ = [ ]

Part IV. DEPENDENCY

For all tasks, except the first task in the sequence, use the table and formulae below to calculate the Task Failure Probability With Formal Dependence ($P_{w/d}$).

If there is a reason why failure on previous tasks should not be considered, such as it is impossible to take the current action unless the previous action has been properly performed, explain here: ________________________

Dependency Condition Table

Condition Number	Crew (same or different)	Time (close in time or not close in time)	Location (same or different)	Cues (additional or no additional)	Dependency	Number of Human Action Failures Rule ☐ - Not Applicable. Why?_________________
1	s	c	s	na	complete	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.**
2				a	complete	
3			d	na	high	
4				a	high	
5		nc	s	na	high	
6				a	moderate	
7			d	na	moderate	
8				a	low	
9	d	c	s	na	moderate	
10				a	moderate	
11			d	na	moderate	
12				a	moderate	
13		nc	s	na	low	
14				a	low	
15			d	na	low	
16				a	low	
17					zero	

Using $P_{w/od}$ = Probability of Task Failure Without Formal Dependence (calculated in Part III):

For Complete Dependence the probability of failure is 1.
For High Dependence the probability of failure is $(1+ P_{w/od})/2$
For Moderate Dependence the probability of failure is $(1+6 \times P_{w/od})/7$
For Low Dependence the probability of failure is $(1+19 \times P_{w/od})/20$
For Zero Dependence the probability of failure is $P_{w/od}$

Calculate $P_{w/d}$ using the appropriate values:

$P_{w/d}$ = (1 + (_______ * _______))/ _______ = [ ]

Reviewer: ____________

Appendix C

Full Power Worksheets for SGTR Example

Appendix C
Full Power Worksheets for SGTR Example

It is assumed that the reactor is at 100% power when the steam generator tube rupture (SGTR) occurs. Given an SGTR, secondary cooling is required for decay heat removal provided a successful reactor trip has occurred. Early core decay heat removal is required for a SGTR event. Successful operation of secondary cooling will start depressurizing the RCS in order to isolate the ruptured steam generator. HPI is used to provide makeup flow to replenish the lost RCS inventory. With HPI and secondary cooling operating, the RCS pressure needs to be reduced below the steam generator relief valve pressure and the steam generator is isolated, then the plant is placed in a stable condition using secondary cooling. If the ruptured steam generator cannot be isolated, then RCS pressure must continue to be lowered in order for shutdown cooling (SDC) to be placed in operation for long-term cooling. Plant stabilization given HPI failed can also be accomplished provided the RCS is depressurized and the steam generator is rapidly isolated.

Feed and bleed cooling could be used to remove decay heat if secondary cooling (i.e., AFW and MFW) is unavailable. For feed and bleed cooling, both PORVs are required to open and remove the decay heat and HPI is required to provide the makeup flow. An operator is required to open the PORVs and PORV block valves if they are closed. The operator controls the flow from the HPI pumps in order to slowly depressurize the RCS. Given the successful operation of feed and bleed, long-term cooling using high-pressure recirculation (HPR) and containment sump recirculation (CSR) is required. These success criteria are consistent within the PWR class G plants.

A number of human actions are associated with the event tree for a generic SGTR at this plant. These include failing to: diagnose, depressurize RCS < SGRV, depressurize after SGRV lift, isolate SG, throttle HPI to reduce pressure, initiate RCS depressurization, etc. Only three of these (failing to diagnose, failing to throttle HPI, and failing to depressurize RCS) are presented here as generalized examples of how to apply SPAR-H worksheets.

HRA Worksheets for At Power

SPAR HUMAN ERROR WORKSHEET

Plant: Plant A Initiating Event: SGTR Basic Event : RCS-XHE-DIAG Event Coder: dk

Basic Event Context: Reactor at 100% Power

Basic Event Description: Operator Fails to Diagnose SGTR

Does this task contain a significant amount of diagnosis activity? YES ☒ (start with Part I–Diagnosis) NO ☐ (skip Part I – Diagnosis; start with Part II – Action) Why? Operator must evaluate a set of parameters (e.g., pressure differences between SGs, rates of increase or decrease of level, etc.). Indications can be masked.

PART I. EVALUATE EACH PSF FOR DIAGNOSIS

A. Evaluate PSFs for the Diagnosis Portion of the Task, If Any.

PSFs	PSF Levels	Multiplier for Diagnosis	Please note specific reasons for PSF level selection in this column.
Available Time	Inadequate time	P(failure) = 1.0 ☐	Based on plant operating characteristics, it is assumed that the crew had adequate (nominal) time.
	Barely adequate time (≈2/3 x nominal)	10 ☐	
	Nominal time	1 ☒	
	Extra time (between 1 and 2 x nominal and > than 30 min)	0.1 ☐	
	Expansive time (> 2 x nominal and > 30 min)	0.01 ☐	
	Insufficient information	1 ☐	
Stress/ Stressors	Extreme	5 ☐	It is assumed that stress will be higher than normal.
	High	2 ☒	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Complexity	Highly complex	5 ☐	Medium tube rupture is moderately complex (feed versus trying to maintain level control).
	Moderately complex	2 ☒	
	Nominal	1 ☐	
	Obvious diagnosis	0.1 ☐	
	Insufficient Information	1 ☐	
Experience/ Training	Low	10 ☐	Simulator training emphasizing diagnosis of SGTR is provided.
	Nominal	1 ☐	
	High	0.5 ☒	
	Insufficient Information	1 ☐	
Procedures	Not available	50 ☐	The EOPs are symptom based.
	Incomplete	20 ☐	
	Available, but poor	5 ☐	
	Nominal	1 ☐	
	Diagnostic/symptom oriented	0.5 ☒	
	Insufficient Information	1 ☐	
Ergonomics/ HMI	Missing/Misleading	50 ☐	Plant-specific SGTR diagnosis simplified by having SG level indication and associated gauges available for comparison.
	Poor	10 ☐	
	Nominal	1 ☐	
	Good	0.5 ☒	
	Insufficient Information	1 ☐	
Fitness for Duty	Unfit	P(failure) = 1.0 ☐	The fitness for duty of the crew is plant and crew specific. This analysis was determined from a generic model and therefore nominal is an appropriate choice.
	Degraded Fitness	5 ☐	
	Nominal	1 ☒	
	Insufficient Information	1 ☐	
Work Processes	Poor	2 ☐	Based upon license examining or review, this plant has good work processes.
	Nominal	1 ☐	
	Good	0.8 ☒	
	Insufficient Information	1 ☐	

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Reviewer: aw

Plant: Plant A Initiating Event: SGTR Basic Event : RCS-XHE-DIAG Event Coder: dk

Basic Event Context: Reactor at 100% Power

Basic Event Description: Operator Fails to Diagnose SGTR

B. Calculate the Diagnosis Failure Probability.

(1) If all PSF ratings are nominal, then the Diagnosis Failure Probability = 1.0E-2
(2) Otherwise, the Diagnosis Failure Probability is: 1.0E-2 x Time x Stress or Stressors x Complexity x Experience or Training x Procedures x Ergonomics or HMI x Fitness for Duty x Processes

Diagnosis: 1.0E-2x **1** x **2** x **2** x **0.5** x **0.5** x **1** x **1** x **0.8** = **0.008**

C. Calculate the Adjustment Factor IF Negative Multiple (≥3) PSFs are Present.

When 3 or more negative PSF influences are present, in lieu of the equation above, you must compute a composite PSF score used in conjunction with the adjustment factor. Negative PSFs are present anytime a multiplier greater than 1 is selected. The Nominal HEP (NHEP) is 1.0E-2 for Diagnosis. The composite PSF score is computed by multiplying all the assigned PSF values. Then the adjustment factor below is applied to compute the HEP:

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

Diagnosis HEP with Adjustment Factor = **N/A**

D. Record Final Diagnosis HEP.

If no adjustment factor was applied, record the value from Part B as your final diagnosis HEP. If an adjustment factor was applied, record the value from Part C.

Final Diagnosis HEP = **0.008**

Reviewer: aw

Plant: Plant A Initiating Event: SGTR Basic Event : RCS-XHE-DIAG Event Coder: dk

Basic Event Context: Reactor at 100% Power

Basic Event Description: Operator Fails to Diagnose SGTR

Part II. EVALUATE EACH PSF FOR ACTION

A. Evaluate PSFs for the Action Portion of the Task, If Any.

PSFs	PSF Levels	Multiplier for Action	Please note specific reasons for PSF level selection in this column.
Available Time	Inadequate time	P(failure) = 1.0 ☐	
	Time available is ≈ the time required	10 ☐	
	Nominal time	1 ☐	
	Time available ≥ 5x the time required	0.1 ☐	
	Time available is ≥ 50x the time required	0.01 ☐	
	Insufficient Information	1 ☐	
Stress/ Stressors	Extreme	5 ☐	
	High	2 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Complexity	Highly complex	5 ☐	
	Moderately complex	2 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Experience/ Training	Low	3 ☐	
	Nominal	1 ☐	
	High	0.5 ☐	
	Insufficient Information	1 ☐	
Procedures	Not available	50 ☐	
	Incomplete	20 ☐	
	Available, but poor	5 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Ergonomics/ HMI	Missing/Misleading	50 ☐	
	Poor	10 ☐	
	Nominal	1 ☐	
	Good	0.5 ☐	
	Insufficient Information	1 ☐	
Fitness for Duty	Unfit	P(failure) = 1.0 ☐	
	Degraded Fitness	5 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Work Processes	Poor	5 ☐	
	Nominal	1 ☐	
	Good	0.5 ☐	
	Insufficient Information	1 ☐	

Reviewer: aw

Plant: Plant A Initiating Event: SGTR Basic Event : RCS-XHE-DIAG Event Coder: dk

Basic Event Context: Reactor at 100% Power

Basic Event Description: Operator Fails to Diagnose SGTR

B. Calculate the Action Failure Probability.

(1) If all PSF ratings are nominal, then the Action Failure Probability = 1.0E-3
(2) Otherwise, the Action Failure Probability is: 1.0E-3 x Time x Stress or Stressors x Complexity x Experience or Training x Procedures x Ergonomics or HMI x Fitness for Duty x Processes

Action: 1.0E-3x ____ x ____ x ____ x ____ x ____ x ____ x ____ x ____ = **N/A**

C. Calculate the Adjustment Factor IF Negative Multiple (≥3) PSFs are Present.

When 3 or more negative PSF influences are present, in lieu of the equation above, you must compute a composite PSF score used in conjunction with the adjustment factor. Negative PSFs are present anytime a multiplier greater than 1 is selected. The Nominal HEP (NHEP) is 1.0E-3 for Action. The composite PSF score is computed by multiplying all the assigned PSF values. Then the adjustment factor below is applied to compute the HEP:

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

Action HEP with Adjustment Factor = **N/A**

D. Record Final Action HEP.

If no adjustment factor was applied, record the value from Part B as your final action HEP. If an adjustment factor was applied, record the value from Part C.

Final Action HEP = **N/A**

Reviewer: aw

Plant: Plant A Initiating Event: SGTR Basic Event : RCS-XHE-DIAG Event Coder: dk

Basic Event Context: Reactor at 100% Power

Basic Event Description: Operator Fails to Diagnose SGTR

PART III. CALCULATE TASK FAILURE PROBABILITY WITHOUT FORMAL DEPENDENCE ($P_{W/OD}$)

Calculate the Task Failure Probability Without Formal Dependence ($P_{w/od}$) by adding the Diagnosis Failure Probability from Part I and the Action Failure Probability from Part II. In instances where an action is required without a diagnosis and there is no dependency, then this step is omitted.

$P_{w/od}$ = Diagnosis HEP **0.008** + Action HEP **0** = **0.008**

Part IV. DEPENDENCY

For all tasks, except the first task in the sequence, use the table and formulae below to calculate the Task Failure Probability With Formal Dependence ($P_{w/d}$).

If there is a reason why failure on previous tasks should not be considered, such as it is impossible to take the current action unless the previous action has been properly performed, explain here**: First task in sequence**

Dependency Condition Table

Condition Number	Crew (same or different)	Time (close in time or not close in time)	Location (same or different)	Cues (additional or no additional)	Dependency	Number of Human Action Failures Rule ☐ - Not Applicable. Why?________________
1	s	c	s	na	complete	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.**
2				a	complete	
3			d	na	high	
4				a	high	
5		nc	s	na	high	
6				a	moderate	
7			d	na	moderate	
8				a	low	
9	d	c	s	na	moderate	
10				a	moderate	
11			d	na	moderate	
12				a	moderate	
13		nc	s	na	low	
14				a	low	
15			d	na	low	
16				a	low	
17					zero ✔	

Using $P_{w/od}$ = Probability of Task Failure Without Formal Dependence (calculated in Part III):

For Complete Dependence the probability of failure is 1.
For High Dependence the probability of failure is $(1+ P_{w/od})/2$
For Moderate Dependence the probability of failure is $(1+6 \times P_{w/od})/7$
For Low Dependence the probability of failure is $(1+19 \times P_{w/od})/20$
For Zero Dependence the probability of failure is $P_{w/od}$ ✔

Calculate $P_{w/d}$ using the appropriate values:

$P_{w/d}$ = (1 + (_______ * _______))/ _______ = **N/A**

Reviewer: aw

HRA Worksheets for At Power
SPAR HUMAN ERROR WORKSHEET

Plant: Plant A **Initiating Event:** SGTR **Basic Event :** HPI-XHE-XM-THTL **Event Coder:** dk

Basic Event Context: HEP2- Reactor at 100% Power

Basic Event Description: Operator Fails to Throttle HPI to Reduce RCS Pressure

Does this task contain a significant amount of diagnosis activity? YES ☐ (start with Part I–Diagnosis) NO ☒ (skip Part I – Diagnosis; start with Part II – Action) Why? Task directed by procedure. Involves turning off pumps or closing down on throttle valve.

PART I. EVALUATE EACH PSF FOR DIAGNOSIS

A. Evaluate PSFs for the Diagnosis Portion of the Task, If Any.

PSFs	PSF Levels	Multiplier for Diagnosis	Please note specific reasons for PSF level selection in this column.
Available Time	Inadequate time	P(failure) = 1.0 ☐	
	Barely adequate time (≈2/3 x nominal)	10 ☐	
	Nominal time	1 ☐	
	Extra time (between 1 and 2 x nominal and > than 30 min)	0.1 ☐	
	Expansive time (> 2 x nominal and > 30 min)	0.01 ☐	
	Insufficient information	1 ☐	
Stress/ Stressors	Extreme	5 ☐	
	High	2 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Complexity	Highly complex	5 ☐	
	Moderately complex	2 ☐	
	Nominal	1 ☐	
	Obvious diagnosis	0.1 ☐	
	Insufficient Information	1 ☐	
Experience/ Training	Low	10 ☐	
	Nominal	1 ☐	
	High	0.5 ☐	
	Insufficient Information	1 ☐	
Procedures	Not available	50 ☐	
	Incomplete	20 ☐	
	Available, but poor	5 ☐	
	Nominal	1 ☐	
	Diagnostic/symptom oriented	0.5 ☐	
	Insufficient Information	1 ☐	
Ergonomics/ HMI	Missing/Misleading	50 ☐	
	Poor	10 ☐	
	Nominal	1 ☐	
	Good	0.5 ☐	
	Insufficient Information	1 ☐	
Fitness for Duty	Unfit	P(failure) = 1.0 ☐	
	Degraded Fitness	5 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Work Processes	Poor	2 ☐	
	Nominal	1 ☐	
	Good	0.8 ☐	
	Insufficient Information	1 ☐	

Rev 1 (1/20/04)

Reviewer: aw

Plant: Plant A Initiating Event: SGTR Basic Event : HPI-XHE-XM-THTL Event Coder: dk

Basic Event Context: HEP2- Reactor at 100% Power

Basic Event Description: Operator Fails to Throttle HPI to Reduce RCS Pressure

B. Calculate the Diagnosis Failure Probability.

(1) If all PSF ratings are nominal, then the Diagnosis Failure Probability = 1.0E-2
(2) Otherwise, the Diagnosis Failure Probability is: 1.0E-2 x Time x Stress or Stressors x Complexity x Experience or Training x Procedures x Ergonomics or HMI x Fitness for Duty x Processes

Diagnosis: 1.0E-2x ____ x ____ x ____ x ____ x ____ x ____ x ____ x ____ = **N/A**

C. Calculate the Adjustment Factor IF Negative Multiple (≥3) PSFs are Present.

When 3 or more negative PSF influences are present, in lieu of the equation above, you must compute a composite PSF score used in conjunction with the adjustment factor. Negative PSFs are present anytime a multiplier greater than 1 is selected. The Nominal HEP (NHEP) is 1.0E-2 for Diagnosis. The composite PSF score is computed by multiplying all the assigned PSF values. Then the adjustment factor below is applied to compute the HEP:

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

Diagnosis HEP with Adjustment Factor = **N/A**

D. Record Final Diagnosis HEP.

If no adjustment factor was applied, record the value from Part B as your final diagnosis HEP. If an adjustment factor was applied, record the value from Part C.

Final Diagnosis HEP = **N/A**

Reviewer: aw

Plant: Plant A Initiating Event: SGTR Basic Event : HPI-XHE-XM-THTL Event Coder: dk

Basic Event Context: HEP2- Reactor at 100% Power

Basic Event Description: Operator Fails to Throttle HPI to Reduce RCS Pressure

Part II. EVALUATE EACH PSF FOR ACTION

A. Evaluate PSFs for the Action Portion of the Task, If Any.

PSFs	PSF Levels	Multiplier for Action		Please note specific reasons for PSF level selection in this column.
Available Time	Inadequate time	P(failure) = 1.0	☐	For a medium break, approximately 4-5 minutes or less is expected to be the time available, but the action only takes a minute to perform.
	Time available is ≈ the time required	10	☐	
	Nominal time	1	☒	
	Time available ≥ 5x the time required	0.1	☐	
	Time available is ≥ 50x the time required	0.01	☐	
	Insufficient Information	1	☐	
Stress/ Stressors	Extreme	5	☐	You know what the problem is now, but the situation remains stressful. Taking action reduces some of the stress you had under diagnosis.
	High	2	☒	
	Nominal	1	☐	
	Insufficient Information	1	☐	
Complexity	Highly complex	5	☐	There is more than one pump in more than one train. May also have to bypass interlocks.
	Moderately complex	2	☒	
	Nominal	1	☐	
	Insufficient Information	1	☐	
Experience/ Training	Low	3	☐	You seem to get SI with almost every event and the crew must deal with it. You do it all the time.
	Nominal	1	☐	
	High	0.5	☒	
	Insufficient Information	1	☐	
Procedures	Not available	50	☐	Expected and trained to do it from memory and then check against procedure.
	Incomplete	20	☐	
	Available, but poor	5	☐	
	Nominal	1	☐	
	Insufficient Information	1	☒	
Ergonomics/ HMI	Missing/Misleading	50	☐	Mimics are good for this. Controls are well labeled. The presentation of the two trains is well laid out. PZR pressure and Rx level can be referenced by the crew.
	Poor	10	☐	
	Nominal	1	☐	
	Good	0.5	☒	
	Insufficient Information	1	☐	
Fitness for Duty	Unfit	P(failure) = 1.0	☐	The fitness for duty of the crew is plant and crew specific. This analysis was determined from a generic model and therefore nominal is an appropriate choice.
	Degraded Fitness	5	☐	
	Nominal	1	☒	
	Insufficient Information	1	☐	
Work Processes	Poor	5	☐	Determined on the basis of analyst evaluation of plant specific information.
	Nominal	1	☐	
	Good	0.5	☒	
	Insufficient Information	1	☐	

Reviewer: aw

Plant: Plant A Initiating Event: SGTR Basic Event : HPI-XHE-XM-THTL Event Coder: dk

Basic Event Context: HEP2- Reactor at 100% Power

Basic Event Description: Operator Fails to Throttle HPI to Reduce RCS Pressure

B. Calculate the Action Failure Probability.

(1) If all PSF ratings are nominal, then the Action Failure Probability = 1.0E-3
(2) Otherwise, the Action Failure Probability is: 1.0E-3 x Time x Stress or Stressors x Complexity x Experience or Training x Procedures x Ergonomics or HMI x Fitness for Duty x Processes

Action: 1.0E-3x **1** x **2** x **2** x **0.5** x **1** x **0.5** x **1** x **0.5** = **0.0005**

C. Calculate the Adjustment Factor IF Negative Multiple (≥3) PSFs are Present.

When 3 or more negative PSF influences are present, in lieu of the equation above, you must compute a composite PSF score used in conjunction with the adjustment factor. Negative PSFs are present anytime a multiplier greater than 1 is selected. The Nominal HEP (NHEP) is 1.0E-3 for Action. The composite PSF score is computed by multiplying all the assigned PSF values. Then the adjustment factor below is applied to compute the HEP:

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

Action HEP with Adjustment Factor = **N/A**

D. Record Final Action HEP.

If no adjustment factor was applied, record the value from Part B as your final action HEP. If an adjustment factor was applied, record the value from Part C.

Final Action HEP = **0.0005**

Reviewer: aw

Plant: Plant A Initiating Event: SGTR Basic Event : HPI-XHE-XM-THTL Event Coder: dk

Basic Event Context: HEP2- Reactor at 100% Power

Basic Event Description: Operator Fails to Throttle HPI to Reduce RCS Pressure

PART III. CALCULATE TASK FAILURE PROBABILITY WITHOUT FORMAL DEPENDENCE ($P_{W/OD}$)

Calculate the Task Failure Probability Without Formal Dependence ($P_{w/od}$) by adding the Diagnosis Failure Probability from Part I and the Action Failure Probability from Part II. In instances where an action is required without a diagnosis and there is no dependency, then this step is omitted.

$P_{w/od}$ = Diagnosis HEP **0** + Action HEP **0.0005** = **0.0005**

Part IV. DEPENDENCY

For all tasks, except the first task in the sequence, use the table and formulae below to calculate the Task Failure Probability With Formal Dependence ($P_{w/d}$).

If there is a reason why failure on previous tasks should not be considered, such as it is impossible to take the current action unless the previous action has been properly performed, explain here: **First HEP is failure to diagnose an SGTR. It is not necessary to diagnose SGTR to reach the need to throttle HPI. You will be directed to throttle HPI from some other emergency operating procedures (EOP) if not the SGTR EOP.**

Dependency Condition Table

Condition Number	Crew (same or different)	Time (close in time or not close in time)	Location (same or different)	Cues (additional or no additional)	Dependency	Number of Human Action Failures Rule ☐ - Not Applicable. Why?________
1	s	c	s	na	complete	When considering recovery in a series e.g., 2nd, 3rd, or 4th checker
2				a	complete	
3			d	na	high	If this error is the **3rd error in the sequence**, then the dependency is at least **moderate**.
4				a	high	
5		nc	s	na	high	
6				a	moderate	
7			d	na	moderate	If this error is the **4th error in the sequence**, then the dependency is at least **high.**
8				a	low	
9	d	c	s	na	moderate	
10				a	moderate	
11			d	na	moderate	
12				a	moderate	
13		nc	s	na	low	
14				a	low	
15			d	na	low	
16				a	low	
17					zero ✔	

Using $P_{w/od}$ = Probability of Task Failure Without Formal Dependence (calculated in Part III):

For Complete Dependence the probability of failure is 1.
For High Dependence the probability of failure is (1+ $P_{w/od}$)/2
For Moderate Dependence the probability of failure is (1+6 x $P_{w/od}$)/7
For Low Dependence the probability of failure is (1+19 x $P_{w/od}$)/20
For Zero Dependence the probability of failure is $P_{w/od}$ ✔

Calculate $P_{w/d}$ using the appropriate values:

$P_{w/d}$ = (1 + (_______ * _______))/ _______ = **N/A**

Reviewer: aw

HRA Worksheets for At Power

SPAR HUMAN ERROR WORKSHEET

Plant: Plant A Initiating Event: SGTR Basic Event : RCS-XHE-XM-SG Event Coder: dk

Basic Event Context: Preceded by Failure to Throttle HPI

Basic Event Description: Failure to Initiate RCS Depressurization

Does this task contain a significant amount of diagnosis activity? YES ☐ (start with Part I–Diagnosis) NO ☒ (skip Part I – Diagnosis; start with Part II – Action) Why? This task involves careful control rather than diagnosis. Elements of diagnosis may be present within individual operator actions as the procedure is followed, but the procedure is prescriptive.

PART I. EVALUATE EACH PSF FOR DIAGNOSIS

A. Evaluate PSFs for the Diagnosis Portion of the Task, If Any.

PSFs	PSF Levels	Multiplier for Diagnosis	Please note specific reasons for PSF level selection in this column.
Available Time	Inadequate time	P(failure) = 1.0 ☐	
	Barely adequate time (≈2/3 x nominal)	10 ☐	
	Nominal time	1 ☐	
	Extra time (between 1 and 2 x nominal and > than 30 min)	0.1 ☐	
	Expansive time (> 2 x nominal and > 30 min)	0.01 ☐	
	Insufficient information	1 ☐	
Stress/ Stressors	Extreme	5 ☐	
	High	2 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Complexity	Highly complex	5 ☐	
	Moderately complex	2 ☐	
	Nominal	1 ☐	
	Obvious diagnosis	0.1 ☐	
	Insufficient Information	1 ☐	
Experience/ Training	Low	10 ☐	
	Nominal	1 ☐	
	High	0.5 ☐	
	Insufficient Information	1 ☐	
Procedures	Not available	50 ☐	
	Incomplete	20 ☐	
	Available, but poor	5 ☐	
	Nominal	1 ☐	
	Diagnostic/symptom oriented	0.5 ☐	
	Insufficient Information	1 ☐	
Ergonomics/ HMI	Missing/Misleading	50 ☐	
	Poor	10 ☐	
	Nominal	1 ☐	
	Good	0.5 ☐	
	Insufficient Information	1 ☐	
Fitness for Duty	Unfit	P(failure) = 1.0 ☐	
	Degraded Fitness	5 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Work Processes	Poor	2 ☐	
	Nominal	1 ☐	
	Good	0.8 ☐	
	Insufficient Information	1 ☐	

Rev 1 (1/20/04)

Reviewer: aw

Plant: Plant A Initiating Event: SGTR Basic Event : RCS-XHE-XM-SG Event Coder: dk

Basic Event Context: Preceded by Failure to Throttle HPI

Basic Event Description: Failure to Initiate RCS Depressurization

B. Calculate the Diagnosis Failure Probability.

(1) If all PSF ratings are nominal, then the Diagnosis Failure Probability = 1.0E-2
(2) Otherwise, the Diagnosis Failure Probability is: 1.0E-2 x Time x Stress or Stressors x Complexity x Experience or Training x Procedures x Ergonomics or HMI x Fitness for Duty x Processes

Diagnosis: 1.0E-2x ____ x ____ x ____ x ____ x ____ x ____ x ____ x ____ = **N/A**

C. Calculate the Adjustment Factor IF Negative Multiple (≥3) PSFs are Present.

When 3 or more negative PSF influences are present, in lieu of the equation above, you must compute a composite PSF score used in conjunction with the adjustment factor. Negative PSFs are present anytime a multiplier greater than 1 is selected. The Nominal HEP (NHEP) is 1.0E-2 for Diagnosis. The composite PSF score is computed by multiplying all the assigned PSF values. Then the adjustment factor below is applied to compute the HEP:

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

Diagnosis HEP with Adjustment Factor = **N/A**

D. Record Final Diagnosis HEP.

If no adjustment factor was applied, record the value from Part B as your final diagnosis HEP. If an adjustment factor was applied, record the value from Part C.

Final Diagnosis HEP = **N/A**

Reviewer: aw

Plant: Plant A Initiating Event: SGTR Basic Event : RCS-XHE-XM-SG Event Coder: dk

Basic Event Context: Preceded by Failure to Throttle HPI

Basic Event Description: Failure to Initiate RCS Depressurization

Part II. EVALUATE EACH PSF FOR ACTION

A. Evaluate PSFs for the Action Portion of the Task, If Any.

PSFs	PSF Levels	Multiplier for Action		Please note specific reasons for PSF level selection in this column.
Available Time	Inadequate time	P(failure) = 1.0	☐	Any leak that will pop a relief valve is time critical.
	Time available is ≈ the time required	10	☒	
	Nominal time	1	☐	
	Time available ≥ 5x the time required	0.1	☐	
	Time available is ≥ 50x the time required	0.01	☐	
	Insufficient Information	1	☐	
Stress/ Stressors	Extreme	5	☒	You've breached a containment barrier and are concerned about a second barrier (relief valves).
	High	2	☐	
	Nominal	1	☐	
	Insufficient Information	1	☐	
Complexity	Highly complex	5	☒	Not a 1-person evolution—1 in charge and 2 workers is barely adequate—often failed on exam—always failed the first time a team of 3 attempts it.
	Moderately complex	2	☐	
	Nominal	1	☐	
	Insufficient Information	1	☐	
Experience/ Training	Low	3	☐	Lots of training on this.
	Nominal	1	☐	
	High	0.5	☒	
	Insufficient Information	1	☐	
Procedures	Not available	50	☐	Sufficient guidelines exist.
	Incomplete	20	☐	
	Available, but poor	5	☐	
	Nominal	1	☒	
	Insufficient Information	1	☐	
Ergonomics/ HMI	Missing/Misleading	50	☐	Task takes place all over control room—requires time sharing between tasks.
	Poor	10	☐	
	Nominal	1	☒	
	Good	0.5	☐	
	Insufficient Information	1	☐	
Fitness for Duty	Unfit	P(failure) = 1.0	☐	The fitness for duty of the crew is plant and crew specific. This analysis was determined from a generic model and therefore nominal is an appropriate choice.
	Degraded Fitness	5	☐	
	Nominal	1	☒	
	Insufficient Information	1	☐	
Work Processes	Poor	5	☐	Plant specific for this facility as determined by review by license examiners.
	Nominal	1	☐	
	Good	0.5	☒	
	Insufficient Information	1	☐	

Reviewer: aw

Plant: Plant A Initiating Event: SGTR Basic Event : RCS-XHE-XM-SG Event Coder: dk

Basic Event Context: Preceded by Failure to Throttle HPI

Basic Event Description: Failure to Initiate RCS Depressurization

B. Calculate the Action Failure Probability.

(1) If all PSF ratings are nominal, then the Action Failure Probability = 1.0E-3
(2) Otherwise, the Action Failure Probability is: 1.0E-3 x Time x Stress or Stressors x Complexity x Experience or Training x Procedures x Ergonomics or HMI x Fitness for Duty x Processes

Action: 1.0E-3x **10** x **5** x **5** x **0.5** x **1** x **1** x **1** x **0.5** = **0.0625**

C. Calculate the Adjustment Factor IF Negative Multiple (≥3) PSFs are Present.

When 3 or more negative PSF influences are present, in lieu of the equation above, you must compute a composite PSF score used in conjunction with the adjustment factor. Negative PSFs are present anytime a multiplier greater than 1 is selected. The Nominal HEP (NHEP) is 1.0E-3 for Action. The composite PSF score is computed by multiplying all the assigned PSF values. Then the adjustment factor below is applied to compute the HEP:

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

Action HEP with Adjustment Factor = **0.0589**

D. Record Final Action HEP.

If no adjustment factor was applied, record the value from Part B as your final action HEP. If an adjustment factor was applied, record the value from Part C.

Final Action HEP = **0.0589**

Reviewer: aw

Plant: Plant A Initiating Event: SGTR Basic Event : RCS-XHE-XM-SG Event Coder: dk

Basic Event Context: Preceded by Failure to Throttle HPI

Basic Event Description: Failure to Initiate RCS Depressurization

PART III. CALCULATE TASK FAILURE PROBABILITY WITHOUT FORMAL DEPENDENCE ($P_{W/OD}$)

Calculate the Task Failure Probability Without Formal Dependence ($P_{w/od}$) by adding the Diagnosis Failure Probability from Part I and the Action Failure Probability from Part II. In instances where an action is required without a diagnosis and there is no dependency, then this step is omitted.

$P_{w/od}$ = Diagnosis HEP 0 + Action HEP 0.0589 = **0.0589**

Part IV. DEPENDENCY

For all tasks, except the first task in the sequence, use the table and formulae below to calculate the Task Failure Probability With Formal Dependence ($P_{w/d}$).

If there is a reason why failure on previous tasks should not be considered, such as it is impossible to take the current action unless the previous action has been properly performed, explain here: ______________________

Dependency Condition Table

Condition Number	Crew (same or different)	Time (close in time or not close in time)	Location (same or different)	Cues (additional or no additional)	Dependency	Number of Human Action Failures Rule ☐ - Not Applicable. Why?_________________
1	s	c	s	na	complete	When considering recovery in a series e.g., 2nd, 3rd, or 4th checker
2				a	complete	
3			d	na	high	If this error is the **3rd error in the sequence**, then the dependency is at least **moderate**.
4				a	high	
5		nc	s	na	high	
6				a	moderate	
7			d	na	moderate	If this error is the **4th error in the sequence**, then the dependency is at least **high.**
8				a	low ✔	
9	d	c	s	na	moderate	
10				a	moderate	
11			d	na	moderate	Although this is the third event and would normally have at least moderate dependency, the previous event had zero dependency. This event is therefore treated as the second event following a zero dependency prior event.
12				a	moderate	
13		nc	s	na	low	
14				a	low	
15			d	na	low	
16				a	low	
17					zero	

Using $P_{w/od}$ = Probability of Task Failure Without Formal Dependence (calculated in Part III):

For Complete Dependence the probability of failure is 1.
For High Dependence the probability of failure is $(1+ P_{w/od})/2$
For Moderate Dependence the probability of failure is $(1+6 \times P_{w/od})/7$
For Low Dependence the probability of failure is $(1+19 \times P_{w/od})/20$ ✔
For Zero Dependence the probability of failure is $P_{w/od}$

Calculate $P_{w/d}$ using the appropriate values:

$P_{w/d}$ = (1 + (19 * 0.0589))/ 20 = **0.105955**

Reviewer: aw

Appendix D

LP/SD Worksheets For PWR LOI with RCS Pressurized

Appendix D
LP/SD Worksheets for PWR Loss of Inventory (LOI) with RCS Pressurized

The scenario evaluated in this report makes use of a low power and shutdown (LP/SD) standardized plant analysis risk model for a U.S. PWR nuclear plant. Specifically, the model was derived from NUREG/CR-6144 (1994) and the at-power operation model for the corresponding plant. The model is organized around a number of plant operating states likely to occur during either (a) refueling, (b) plant maintenance with drained reactor coolant system, (c) nondrained maintenance that uses the RHR system for removal of decay heat, or (d) nondrained maintenance without using the RHR system. Event trees, fault trees, and basic event data were compiled but are not part of this report. The SPAR application in the following corresponds to HEPs that would be included as part of SPAR basic events.

The scenario selected refers to a loss of inventory initiating event that leads to a reduction in RCS inventory that in turn, leads to a loss of RHR. A loss of inventory event tree is presented as Table D-1. During the formal analysis, the loss of inventory event tree was broken into two separate event trees because of differences in the initiating events. One tree uses a demand related initiating event, the other an hourly-initiating event. The demand tree refers to over draining events when the RCS is being reduced to mid-loop. The event tree reviewed for purposes of SPAR-H refinement and application was from the hourly group, where loss of inventory occurs with the RCS pressurized. One of the prominent events is the success or failure of RCS make-up by the operators. Success implies that make-up water is being provided to the RCS by either one train of HPHPSI, both trains of CVCS, or one train of the low-pressure injection (LPI). Success requires an operator to start and align the suction of the injection pumps to the RWST and to align the discharge to the RCS cold legs. Similar considerations were made when determining the HEPs for all basic events. Fault trees underlying individual basic events were also determined but are not presented as part of this report. These trains include operator failures as well as component unavailability information, and time window information usually represented at this level of analysis. As with any event analysis, the HEP determined by the SPAR-H method only identifies the human error contribution to the basic event frequency.

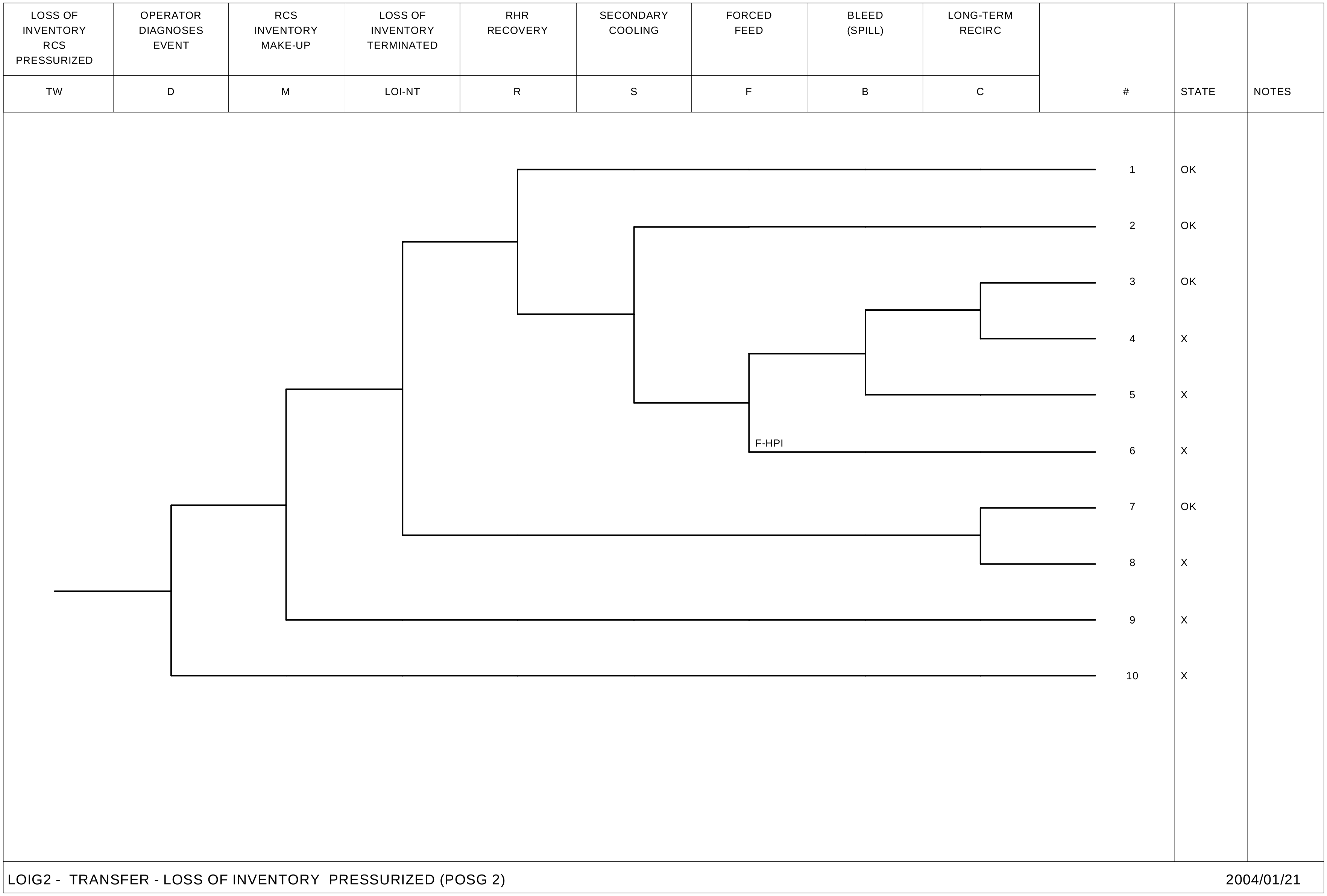

Figure D-1. Loss of inventory event tree with RCS pressurized for a nuclear power plant.

HRA Worksheets for LP/SD

SPAR Human Error Worksheet

Plant: Plant B Initiating Event: LOI Basic Event : RHR-XHE-DIAP2 Event Coder: dk

Basic Event Context: Loss of Inventory with RCS Pressurized

Basic Event Description: Operator Fails to Diagnose Loss of Inventory (1st Event)

Does this task contain a significant amount of diagnosis activity? YES ☒ (start with Part I–Diagnosis) NO ☐ (skip Part I – Diagnosis; start with Part II – Action) Why?____________________

PART I. EVALUATE EACH PSF FOR DIAGNOSIS

A. Evaluate PSFs for the Diagnosis Portion of the Task.

PSFs	PSF Levels	Multiplier for Diagnosis		Please note specific reasons for PSF level selection in this column.
Available Time	Inadequate time	P(failure) = 1.0	☐	Given that an isolated leak rate is occurring.
	Barely adequate time (≈ 2/3 x nominal)	10	☐	
	Nominal time	1	☒	
	Extra time (between 1and 2 x nominal and > 30 min)	0.1	☐	
	Expansive time > 2 x nominal & > 30 min	0.1 to 0.01	☐	
	Insufficient Information	1	☐	
Stress/ Stressors	Extreme	5	☐	Extreme stress is too dramatic for shutdown activity. Some stress related to concern for cavitating the centrifical shutdown cooling pumps.
	High	2	☒	
	Nominal	1	☐	
	Insufficient Information	1	☐	
Complexity	Highly complex	5	☐	If plant is at mid loop, operators are balancing water and air without a lot of inertia.
	Moderately complex	2	☐	
	Nominal	1	☒	
	Obvious diagnosis	0.1	☐	
	Insufficient Information	1	☐	
Experience/ Training	Low	10	☐	Extensive training and experience.
	Nominal	1	☐	
	High	0.5	☒	
	Insufficient Information	1	☐	
Procedures	Not available	50	☐	Emergency Operating Procedures (EOPs) are symptom-based.
	Incomplete	20	☐	
	Available, but poor	5	☐	
	Nominal	1	☐	
	Diagnostic/symptom oriented	0.5	☒	
	Insufficient Information	1	☐	
Ergonomics/ HMI	Missing/Misleading	50	☐	System less well designed for LP/SD activities. The reactor vessel level monitoring system is assumed to be available.
	Poor	10	☒	
	Nominal	1	☐	
	Good	0.5	☐	
	Insufficient Information	1	☐	
Fitness for Duty	Unfit	P(failure) = 1.0	☐	The fitness for duty of the crew is plant and crew specific. This analysis was determined from a generic model and therefore nominal is an appropriate choice.
	Degraded Fitness	5	☐	
	Nominal	1	☒	
	Insufficient Information	1	☐	
Work Processes	Poor	2	☐	The work processes are plant and crew specific. This analysis was determined from a generic model and therefore nominal is an appropriate choice.
	Nominal	1	☒	
	Good	0.8	☐	
	Insufficient Information	1	☐	

Rev 1 (1/20/04)

Reviewer: aw

Plant: Plant B Initiating Event: LOI Basic Event : RHR-XHE-DIAP2 Event Coder: dk

Basic Event Context: Loss of Inventory with RCS Pressurized

Basic Event Description: Operator Fails to Diagnose Loss of Inventory (1st Event)

B. Calculate the Diagnosis Failure Probability.

(1) If all PSF ratings are nominal, then the Diagnosis Failure Probability = 1.0E-2
(2) Otherwise, the Diagnosis Failure Probability is: 1.0E-2 x Time x Stress or Stressors x Complexity x Experience or Training x Procedures x Ergonomics or HMI x Fitness for Duty x Processes

Diagnosis: 1.0E-2x **1** x **2** x **1** x **0.5** x **0.5** x **10** x **1** x **1** = **0.05**

C. Calculate the Adjustment Factor IF Negative Multiple (≥3) PSFs are Present.

When 3 or more negative PSF influences are present, in lieu of the equation above, you must compute a composite PSF score used in conjunction with the adjustment factor. Negative PSFs are present anytime a multiplier greater than 1 is selected. The Nominal HEP (NHEP) is 1.0E-2 for Diagnosis. The composite PSF score is computed by multiplying all the assigned PSF values. Then the adjustment factor below is applied to compute the HEP:

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

Diagnosis HEP with Adjustment Factor = **N/A**

D. Record Final Diagnosis HEP.

If no adjustment factor was applied, record the value from Part B as your final diagnosis HEP. If an adjustment factor was applied, record the value from Part C.

Final Diagnosis HEP = **0.05**

Reviewer: aw

Plant: Plant B Initiating Event: LOI Basic Event : RHR-XHE-DIAP2 Event Coder: dk

Basic Event Context: Loss of Inventory with RCS Pressurized

Basic Event Description: Operator Fails to Diagnose Loss of Inventory (1st Event)

Part II. EVALUATE EACH PSF FOR ACTION

A. Evaluate PSFs for the Action Portion of the Task, If Any.

PSFs	PSF Levels	Multiplier for Action	Please note specific reasons for PSF level selection in this column.
Available Time	Inadequate time	P(failure) = 1.0 ☐	
	Time available is ≈ the time required	10 ☐	
	Nominal time	1 ☐	
	Time available ≥ 5x the time required	0.1 ☐	
	Time available is ≥ 50x the time required	0.01 ☐	
	Insufficient Information	1 ☐	
Stress/ Stressors	Extreme	5 ☐	
	High	2 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Complexity	Highly complex	5 ☐	
	Moderately complex	2 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Experience/ Training	Low	3 ☐	
	Nominal	1 ☐	
	High	0.5 ☐	
	Insufficient Information	1 ☐	
Procedures	Not available	50 ☐	
	Incomplete	20 ☐	
	Available, but poor	5 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Ergonomics/ HMI	Missing/Misleading	50 ☐	
	Poor	10 ☐	
	Nominal	1 ☐	
	Good	0.5 ☐	
	Insufficient Information	1 ☐	
Fitness for Duty	Unfit	P(failure) = 1.0 ☐	
	Degraded Fitness	5 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Work Processes	Poor	5 ☐	
	Nominal	1 ☐	
	Good	0.5 ☐	
	Insufficient Information	1 ☐	

Reviewer: aw

Plant: Plant B Initiating Event: LOI Basic Event : RHR-XHE-DIAP2 Event Coder: dk

Basic Event Context: Loss of Inventory with RCS Pressurized

Basic Event Description: Operator Fails to Diagnose Loss of Inventory (1st Event)

B. Calculate the Action Failure Probability.

(1) If all PSF ratings are nominal, then the Action Failure Probability = 1.0E-3
(2) Otherwise, the Action Failure Probability is: 1.0E-3 x Time x Stress or Stressors x Complexity x Experience or Training x Procedures x Ergonomics or HMI x Fitness for Duty x Processes

Action: 1.0E-3x ____ x ____ x ____ x ____ x ____ x ____ x ____ x ____ = **N/A**

C. Calculate the Adjustment Factor IF Negative Multiple (≥3) PSFs are Present.

When 3 or more negative PSF influences are present, in lieu of the equation above, you must compute a composite PSF score used in conjunction with the adjustment factor. Negative PSFs are present anytime a multiplier greater than 1 is selected. The Nominal HEP (NHEP) is 1.0E-3 for Action. The composite PSF score is computed by multiplying all the assigned PSF values. Then the adjustment factor below is applied to compute the HEP:

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

Action HEP with Adjustment Factor = **N/A**

D. Record Final Action HEP.

If no adjustment factor was applied, record the value from Part B as your final action HEP. If an adjustment factor was applied, record the value from Part C.

Final Action HEP = **N/A**

Reviewer: aw

Plant: Plant B Initiating Event: LOI Basic Event : RHR-XHE-DIAP2 Event Coder: dk

Basic Event Context: Loss of Inventory with RCS Pressurized

Basic Event Description: Operator Fails to Diagnose Loss of Inventory (1st Event)

PART III. CALCULATE TASK FAILURE PROBABILITY WITHOUT FORMAL DEPENDENCE ($P_{W/OD}$)

Calculate the Task Failure Probability Without Formal Dependence ($P_{w/od}$) by adding the Diagnosis Failure Probability from Part I and the Action Failure Probability from Part II. In instances where an action is required without a diagnosis and there is no dependency, then this step is omitted.

$P_{w/od}$ = Diagnosis HEP 0.05 + Action HEP 0 = **0.05**

Part IV. DEPENDENCY

For all tasks, except the first task in the sequence, use the table and formulae below to calculate the Task Failure Probability With Formal Dependence ($P_{w/d}$).

If there is a reason why failure on previous tasks should not be considered, such as it is impossible to take the current action unless the previous action has been properly performed, explain here: **This task is first in the event tree; no previous human actions considered.**

Dependency Condition Table

Condition Number	Crew (same or different)	Time (close in time or not close in time)	Location (same or different)	Cues (additional or no additional)	Dependency	Number of Human Action Failures Rule ☐ - Not Applicable. Why?________________
1	s	c	s	na	complete	When considering recovery in a series e.g., 2nd, 3rd, or 4th checker
2				a	complete	
3			d	na	high	If this error is the **3rd error in the sequence**, then the dependency is at least **moderate**.
4				a	high	
5		nc	s	na	high	
6				a	moderate	
7			d	na	moderate	If this error is the **4th error in the sequence**, then the dependency is at least **high.**
8				a	low	
9	d	c	s	na	moderate	
10				a	moderate	
11			d	na	moderate	
12				a	moderate	
13		nc	s	na	low	
14				a	low	
15			d	na	low	
16				a	low	
17					zero ✔	

Using $P_{w/od}$ = Probability of Task Failure Without Formal Dependence (calculated in Part III):

For Complete Dependence the probability of failure is 1.
For High Dependence the probability of failure is $(1+ P_{w/od})/2$
For Moderate Dependence the probability of failure is $(1+6 \times P_{w/od})/7$
For Low Dependence the probability of failure is $(1+19 \times P_{w/od})/20$
For Zero Dependence the probability of failure is $P_{w/od}$ ✔

Calculate $P_{w/d}$ using the appropriate values:

$P_{w/d} = (1 + (\_\_\_\_\_ * \_\_\_\_\_))/ \_\_\_\_\_ =$ **N/A**

Reviewer: aw

HRA Worksheets for LP/SD

SPAR Human Error Worksheet

Plant: Plant B Initiating Event: LOI Basic Event : RHR-XHE-LOI123 Event Coder: dk

Basic Event Context: Loss of Inventory with RCS Pressurized

Basic Event Description: Failure to Recover RHR

Does this task contain a significant amount of diagnosis activity? YES ☒ (start with Part I–Diagnosis) NO ☐ (skip Part I – Diagnosis; start with Part II – Action) Why?____________________

PART I. EVALUATE EACH PSF FOR DIAGNOSIS

A. Evaluate PSFs for the Diagnosis Portion of the Task.

PSFs	PSF Levels	Multiplier for Diagnosis	Please note specific reasons for PSF level selection in this column.
Available Time	Inadequate time	P(failure) = 1.0 ☐	Given than an isolatable leak rate is occurring. Time to boil can vary as can time to uncover the core.
	Barely adequate time (≈ 2/3 x nominal)	10 ☐	
	Nominal time	1 ☒	
	Extra time (between 1and 2 x nominal and > 30 min)	0.1 ☐	
	Expansive time > 2 x nominal & > 30 min	0.1 to 0.01 ☐	
	Insufficient Information	1 ☐	
Stress/ Stressors	Extreme	5 ☐	Extreme stress is too dramatic for shutdown activity.
	High	2 ☒	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Complexity	Highly complex	5 ☐	Based on the generic model, it is assumed that the diagnosis task is not difficult and not especially complex.
	Moderately complex	2 ☐	
	Nominal	1 ☒	
	Obvious diagnosis	0.1 ☐	
	Insufficient Information	1 ☐	
Experience/ Training	Low	10 ☐	Extensive training and experience.
	Nominal	1 ☐	
	High	0.5 ☒	
	Insufficient Information	1 ☐	
Procedures	Not available	50 ☐	EOPs are symptom based.
	Incomplete	20 ☐	
	Available, but poor	5 ☐	
	Nominal	1 ☐	
	Diagnostic/symptom oriented	0.5 ☒	
	Insufficient Information	1 ☐	
Ergonomics/ HMI	Missing/Misleading	50 ☐	System less well-designed for LP/SD activities. Operators need to look at AMMeter oscillations as an indirect pump status indication.
	Poor	10 ☒	
	Nominal	1 ☐	
	Good	0.5 ☐	
	Insufficient Information	1 ☐	
Fitness for Duty	Unfit	P(failure) = 1.0 ☐	The fitness for duty of the crew is plant and crew specific. This analysis was determined from a generic model and therefore nominal is an appropriate choice.
	Degraded Fitness	5 ☐	
	Nominal	1 ☒	
	Insufficient Information	1 ☐	
Work Processes	Poor	2 ☐	The work processes are plant and crew specific. This analysis was determined from a generic model and therefore nominal is an appropriate choice.
	Nominal	1 ☒	
	Good	0.8 ☐	
	Insufficient Information	1 ☐	

Rev 1 (1/20/04)

Reviewer: aw

Plant: Plant B Initiating Event: LOI Basic Event : RHR-XHE-LOI123 Event Coder: dk

Basic Event Context: Loss of Inventory with RCS Pressurized

Basic Event Description: Failure to Recover RHR

B. Calculate the Diagnosis Failure Probability.

(1) If all PSF ratings are nominal, then the Diagnosis Failure Probability = 1.0E-2
(2) Otherwise, the Diagnosis Failure Probability is: 1.0E-2 x Time x Stress or Stressors x Complexity x Experience or Training x Procedures x Ergonomics or HMI x Fitness for Duty x Processes

Diagnosis: 1.0E-2x **1** x **2** x **1** x **0.5** x **0.5** x **10** x **1** x **1** = **0.05**

C. Calculate the Adjustment Factor IF Negative Multiple (≥3) PSFs are Present.

When 3 or more negative PSF influences are present, in lieu of the equation above, you must compute a composite PSF score used in conjunction with the adjustment factor. Negative PSFs are present anytime a multiplier greater than 1 is selected. The Nominal HEP (NHEP) is 1.0E-2 for Diagnosis. The composite PSF score is computed by multiplying all the assigned PSF values. Then the adjustment factor below is applied to compute the HEP:

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

Diagnosis HEP with Adjustment Factor = **N/A**

D. Record Final Diagnosis HEP.

If no adjustment factor was applied, record the value from Part B as your final diagnosis HEP. If an adjustment factor was applied, record the value from Part C.

Final Diagnosis HEP = **0.05**

Reviewer: aw

Plant: Plant B Initiating Event: LOI Basic Event : RHR-XHE-LOI123 Event Coder: dk

Basic Event Context: Loss of Inventory with RCS Pressurized

Basic Event Description: Failure to Recover RHR

Part II. EVALUATE EACH PSF FOR ACTION

A. Evaluate PSFs for the Action Portion of the Task, If Any.

PSFs	PSF Levels	Multiplier for Action		Please note specific reasons for PSF level selection in this column.
Available Time	Inadequate time	P(failure) = 1.0	☐	The time window afforded by plant operating state may affect new response but by a factor of no more than 1 to 2.
	Time available is ≈ the time required	10	☐	
	Nominal time	1	☒	
	Time available ≥ 5x the time required	0.1	☐	
	Time available is ≥ 50x the time required	0.01	☐	
	Insufficient Information	1	☐	
Stress/ Stressors	Extreme	5	☐	Stress is assumed to decrease from the level during diagnosis to be nominal when performing the action.
	High	2	☐	
	Nominal	1	☒	
	Insufficient Information	1	☐	
Complexity	Highly complex	5	☐	Based on the generic model, it is assumed that the action task is not difficult and not especially complex.
	Moderately complex	2	☐	
	Nominal	1	☒	
	Insufficient Information	1	☐	
Experience/ Training	Low	3	☐	Crew is well trained on residual heat removal (RHR) for "at power" context.
	Nominal	1	☐	
	High	0.5	☒	
	Insufficient Information	1	☐	
Procedures	Not available	50	☐	Not as well developed for shutdown activities.
	Incomplete	20	☐	
	Available, but poor	5	☒	
	Nominal	1	☐	
	Insufficient Information	1	☐	
Ergonomics/ HMI	Missing/Misleading	50	☐	Once diagnosed, good support for corrective action; appropriate feedback is provided for this task.
	Poor	10	☐	
	Nominal	1	☐	
	Good	0.5	☒	
	Insufficient Information	1	☐	
Fitness for Duty	Unfit	P(failure) = 1.0	☐	The fitness for duty of the crew is plant and crew specific. This analysis was determined from a generic model and therefore nominal is an appropriate choice.
	Degraded Fitness	5	☐	
	Nominal	1	☒	
	Insufficient Information	1	☐	
Work Processes	Poor	5	☐	The work processes are plant and crew specific. This analysis was determined from a generic model and therefore nominal is an appropriate choice.
	Nominal	1	☒	
	Good	0.5	☐	
	Insufficient Information	1	☐	

Reviewer: aw

Plant: Plant B Initiating Event: LOI Basic Event : RHR-XHE-LOI123 Event Coder: dk

Basic Event Context: Loss of Inventory with RCS Pressurized

Basic Event Description: Failure to Recover RHR

B. Calculate the Action Failure Probability.

(1) If all PSF ratings are nominal, then the Action Failure Probability = 1.0E-3
(2) Otherwise, the Action Failure Probability is: 1.0E-3 x Time x Stress or Stressors x Complexity x Experience or Training x Procedures x Ergonomics or HMI x Fitness for Duty x Processes

Action: 1.0E-3x **1** x **1** x **1** x **0.5** x **5** x **0.5** x **1** x **1** = **0.00125**

C. Calculate the Adjustment Factor IF Negative Multiple (≥3) PSFs are Present.

When 3 or more negative PSF influences are present, in lieu of the equation above, you must compute a composite PSF score used in conjunction with the adjustment factor. Negative PSFs are present anytime a multiplier greater than 1 is selected. The Nominal HEP (NHEP) is 1.0E-3 for Action. The composite PSF score is computed by multiplying all the assigned PSF values. Then the adjustment factor below is applied to compute the HEP:

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

Action HEP with Adjustment Factor = **N/A**

D. Record Final Action HEP.

If no adjustment factor was applied, record the value from Part B as your final action HEP. If an adjustment factor was applied, record the value from Part C.

Final Action HEP = **0.00125**

Reviewer: aw

Plant: Plant B Initiating Event: LOI Basic Event : RHR-XHE-LOI123 Event Coder: dk

Basic Event Context: Loss of Inventory with RCS Pressurized

Basic Event Description: Failure to Recover RHR

PART III. CALCULATE TASK FAILURE PROBABILITY WITHOUT FORMAL DEPENDENCE ($P_{W/OD}$)

Calculate the Task Failure Probability Without Formal Dependence ($P_{w/od}$) by adding the Diagnosis Failure Probability from Part I and the Action Failure Probability from Part II. In instances where an action is required without a diagnosis and there is no dependency, then this step is omitted.

$P_{w/od}$ = Diagnosis HEP **0.05** + Action HEP **0.00125** = **0.05125**

Part IV. DEPENDENCY

For all tasks, except the first task in the sequence, use the table and formulae below to calculate the Task Failure Probability With Formal Dependence ($P_{w/d}$).

If there is a reason why failure on previous tasks should not be considered, such as it is impossible to take the current action unless the previous action has been properly performed, explain here: ______________________

Dependency Condition Table

Condition Number	Crew (same or different)	Time (close in time or not close in time)	Location (same or different)	Cues (additional or no additional)	Dependency	Number of Human Action Failures Rule ☐ - Not Applicable. Why?________________
1	s	c	s	na	complete	When considering recovery in a series e.g., 2nd, 3rd, or 4th checker
2				a	complete	
3			d	na	high	If this error is the **3rd error in the sequence**, then the dependency is at least **moderate**.
4				a	high	
5		nc	s	na	high	
6				a	moderate	
7			d	na	moderate	If this error is the **4th error in the sequence**, then the dependency is at least **high.**
8				a	low	
9	d	c	s	na	moderate ✔	
10				a	moderate	
11			d	na	moderate	
12				a	moderate	
13		nc	s	na	low	
14				a	low	
15			d	na	low	
16				a	low	
17					zero	

Using $P_{w/od}$ = Probability of Task Failure Without Formal Dependence (calculated in Part III):

For Complete Dependence the probability of failure is 1.
For High Dependence the probability of failure is $(1+ P_{w/od})/2$
For Moderate Dependence the probability of failure is $(1+6 \times P_{w/od})/7$ ✔
For Low Dependence the probability of failure is $(1+19 \times P_{w/od})/20$
For Zero Dependence the probability of failure is $P_{w/od}$

Calculate $P_{w/d}$ using the appropriate values:

$P_{w/d}$ = (1 + (**6** * **0.05125**))/ **7** = **0.187**

Reviewer: aw

HRA Worksheets for LP/SD

SPAR Human Error Worksheet

Plant: Plant B Initiating Event: LOI Basic Event : RHR-XHE-XM-FB Event Coder: dk

Basic Event Context: Loss of Inventory with RCS Pressurized/Failure to Start Pump

Basic Event Description: Failure to Force Feed

Does this task contain a significant amount of diagnosis activity? YES ☒ (start with Part I–Diagnosis) NO ☐ (skip Part I – Diagnosis; start with Part II – Action) Why?

PART I. EVALUATE EACH PSF FOR DIAGNOSIS

A. Evaluate PSFs for the Diagnosis Portion of the Task.

PSFs	PSF Levels	Multiplier for Diagnosis	Please note specific reasons for PSF level selection in this column.
Available Time	Inadequate time	P(failure) = 1.0 ☐	Given that an isolatable leak rate is occurring.
	Barely adequate time (≈ 2/3 x nominal)	10 ☐	
	Nominal time	1 ☒	
	Extra time (between 1and 2 x nominal and > 30 min)	0.1 ☐	
	Expansive time > 2 x nominal & > 30 min	0.1 to 0.01 ☐	
	Insufficient Information	1 ☐	
Stress/ Stressors	Extreme	5 ☐	Extreme stress is too dramatic for shutdown activity.
	High	2 ☒	
	Nominal	1 ☐	
	Insufficient Information	1 ☐	
Complexity	Highly complex	5 ☐	Based on the generic model, it is assumed that the diagnosis task is not difficult and not especially complex.
	Moderately complex	2 ☐	
	Nominal	1 ☒	
	Obvious diagnosis	0.1 ☐	
	Insufficient Information	1 ☐	
Experience/ Training	Low	10 ☐	Extensive training and experience.
	Nominal	1 ☐	
	High	0.5 ☒	
	Insufficient Information	1 ☐	
Procedures	Not available	50 ☐	EOPs are symptom based.
	Incomplete	20 ☐	
	Available, but poor	5 ☐	
	Nominal	1 ☐	
	Diagnostic/symptom oriented	0.5 ☒	
	Insufficient Information	1 ☐	
Ergonomics/ HMI	Missing/Misleading	50 ☐	System less well-designed for LP/SD activities. Key indication for the operators may include pressurizer level, reactor level, and general mid loop instrumentation.
	Poor	10 ☒	
	Nominal	1 ☐	
	Good	0.5 ☐	
	Insufficient Information	1 ☐	
Fitness for Duty	Unfit	P(failure) = 1.0 ☐	The fitness for duty of the crew is plant and crew specific. This analysis was determined from a generic model and therefore nominal is an appropriate choice.
	Degraded Fitness	5 ☐	
	Nominal	1 ☒	
	Insufficient Information	1 ☐	
Work Processes	Poor	2 ☐	Work processes are plant and crew specific. This analysis was determined from a generic model and therefore nominal is an appropriate choice.
	Nominal	1 ☒	
	Good	0.8 ☐	
	Insufficient Information	1 ☐	

Rev 1 (1/20/04)

Reviewer: aw

Basic Event Context: Loss of Inventory with RCS Pressurized/Failure to Start Pump

Basic Event Description: Failure to Force Feed

B. Calculate the Diagnosis Failure Probability.

(1) If all PSF ratings are nominal, then the Diagnosis Failure Probability = 1.0E-2
(2) Otherwise, the Diagnosis Failure Probability is: 1.0E-2 x Time x Stress or Stressors x Complexity x Experience or Training x Procedures x Ergonomics or HMI x Fitness for Duty x Processes

Diagnosis: 1.0E-2x **1** x **2** x **1** x **0.5** x **0.5** x **10** x **1** x **1** = **0.05**

C. Calculate the Adjustment Factor IF Negative Multiple (≥3) PSFs are Present.

When 3 or more negative PSF influences are present, in lieu of the equation above, you must compute a composite PSF score used in conjunction with the adjustment factor. Negative PSFs are present anytime a multiplier greater than 1 is selected. The Nominal HEP (NHEP) is 1.0E-2 for Diagnosis. The composite PSF score is computed by multiplying all the assigned PSF values. Then the adjustment factor below is applied to compute the HEP:

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

Diagnosis HEP with Adjustment Factor = **N/A**

D. Record Final Diagnosis HEP.

If no adjustment factor was applied, record the value from Part B as your final diagnosis HEP. If an adjustment factor was applied, record the value from Part C.

Final Diagnosis HEP = **0.05**

Reviewer: aw

Basic Event Context: Loss of Inventory with RCS Pressurized/Failure to Start Pump

Basic Event Description: Failure to Force Feed

Part II. EVALUATE EACH PSF FOR ACTION

A. Evaluate PSFs for the Action Portion of the Task, If Any.

PSFs	PSF Levels	Multiplier for Action		Please note specific reasons for PSF level selection in this column.
Available Time	Inadequate time	P(failure) = 1.0	☐	Based upon the leak rate, ample time available to resolve leak.
	Time available is ≈ the time required	10	☐	
	Nominal time	1	☐	
	Time available ≥ 5x the time required	0.1	☒	
	Time available is ≥ 50x the time required	0.01	☐	
	Insufficient Information	1	☐	
Stress/ Stressors	Extreme	5	☐	Task action is easier than diagnosis; therefore, nominal stress is assumed.
	High	2	☐	
	Nominal	1	☒	
	Insufficient Information	1	☐	
Complexity	Highly complex	5	☐	Moderately complex actions are required to force feed.
	Moderately complex	2	☒	
	Nominal	1	☐	
	Insufficient Information	1	☐	
Experience/ Training	Low	3	☐	Crew is well trained.
	Nominal	1	☐	
	High	0.5	☒	
	Insufficient Information	1	☐	
Procedures	Not available	50	☐	Procedures are sufficient for the action required.
	Incomplete	20	☐	
	Available, but poor	5	☐	
	Nominal	1	☒	
	Insufficient Information	1	☐	
Ergonomics/ HMI	Missing/Misleading	50	☐	Once diagnosed, good support for corrective action; appropriate feedback provided for task.
	Poor	10	☐	
	Nominal	1	☒	
	Good	0.5	☐	
	Insufficient Information	1	☐	
Fitness for Duty	Unfit	P(failure) = 1.0	☐	The fitness for duty of the crew is plant and crew specific. This analysis was determined from a generic model and therefore nominal is an appropriate choice.
	Degraded Fitness	5	☐	
	Nominal	1	☒	
	Insufficient Information	1	☐	
Work Processes	Poor	5	☐	The work processes are plant and crew specific. This analysis was determined from a generic model and therefore nominal is an appropriate choice.
	Nominal	1	☒	
	Good	0.5	☐	
	Insufficient Information	1	☐	

Reviewer: aw

Plant: Plant B Initiating Event: LOI Basic Event : RHR-XHE-XM-FB Event Coder: dk

Basic Event Context: Loss of Inventory with RCS Pressurized/Failure to Start Pump

Basic Event Description: Failure to Force Feed

B. Calculate the Action Failure Probability.

(1) If all PSF ratings are nominal, then the Action Failure Probability = 1.0E-3
(2) Otherwise, the Action Failure Probability is: 1.0E-3 x Time x Stress or Stressors x Complexity x Experience or Training x Procedures x Ergonomics or HMI x Fitness for Duty x Processes

Action: 1.0E-3x **0.1** x **1** x **2** x **0.5** x **1** x **1** x **1** x **1** = **0.0001**

C. Calculate the Adjustment Factor IF Negative Multiple (≥3) PSFs are Present.

When 3 or more negative PSF influences are present, in lieu of the equation above, you must compute a composite PSF score used in conjunction with the adjustment factor. Negative PSFs are present anytime a multiplier greater than 1 is selected. The Nominal HEP (NHEP) is 1.0E-3 for Action. The composite PSF score is computed by multiplying all the assigned PSF values. Then the adjustment factor below is applied to compute the HEP:

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

Action HEP with Adjustment Factor = **N/A**

D. Record Final Action HEP.

If no adjustment factor was applied, record the value from Part B as your final action HEP. If an adjustment factor was applied, record the value from Part C.

Final Action HEP = **0.0001**

Reviewer: aw

Plant: Plant B Initiating Event: LOI Basic Event : RHR-XHE-XM-FB Event Coder: dk

Basic Event Context: Loss of Inventory with RCS Pressurized/Failure to Start Pump

Basic Event Description: Failure to Force Feed

PART III. CALCULATE TASK FAILURE PROBABILITY WITHOUT FORMAL DEPENDENCE ($P_{W/OD}$)

Calculate the Task Failure Probability Without Formal Dependence ($P_{w/od}$) by adding the Diagnosis Failure Probability from Part I and the Action Failure Probability from Part II. In instances where an action is required without a diagnosis and there is no dependency, then this step is omitted.

$P_{w/od}$ = Diagnosis HEP **0.05** + Action HEP **0.0001** = **0.0501**

Part IV. DEPENDENCY

For all tasks, except the first task in the sequence, use the table and formulae below to calculate the Task Failure Probability With Formal Dependence ($P_{w/d}$).

If there is a reason why failure on previous tasks should not be considered, such as it is impossible to take the current action unless the previous action has been properly performed, explain here: ________________________

Dependency Condition Table

Condition Number	Crew (same or different)	Time (close in time or not close in time)	Location (same or different)	Cues (additional or no additional)	Dependency	Number of Human Action Failures Rule ☐ - Not Applicable. Why?_________________
1	s	c	s	na	complete ✔	When considering recovery in a series e.g., 2nd, 3rd, or 4th checker
2				a	complete	
3			d	na	high	If this error is the **3rd error in the sequence**, then the dependency is at least **moderate**.
4				a	high	
5		nc	s	na	high	
6				a	moderate	
7			d	na	moderate	If this error is the **4th error in the sequence**, then the dependency is at least **high.**
8				a	low	
9	d	c	s	na	moderate	
10				a	moderate	
11			d	na	moderate	
12				a	moderate	
13		nc	s	na	low	
14				a	low	
15			d	na	low	
16				a	low	
17					zero	

Using $P_{w/od}$ = Probability of Task Failure Without Formal Dependence (calculated in Part III):

For Complete Dependence the probability of failure is 1. ✔
For High Dependence the probability of failure is $(1+ P_{w/od})/2$
For Moderate Dependence the probability of failure is $(1+6 \times P_{w/od})/7$
For Low Dependence the probability of failure is $(1+19 \times P_{w/od})/20$
For Zero Dependence the probability of failure is $P_{w/od}$

Calculate $P_{w/d}$ using the appropriate values:

$P_{w/d}$ = (1 + (_______ * _______))/ _______ = **1.0**

Reviewer: aw

Appendix E

Worksheets for Dry Cask

Appendix E
Worksheets for Dry Cask

The following three examples are SPAR-H applications for a screening HRA performed on dry cask storage operations for spent commercial reactor fuel. The dry cask storage operation includes loading spent fuel assemblies into a canister contained in a cement cask under water in the spent fuel pool, placing the lid with drain pipe assembly on the canister, removing the cask from the pool, sealing the canister, drying and inserting the canister, closing the cask, drying the cask annulus, and moving the cask to an outdoor storage pad.

The first example is the SPAR-H worksheet for the task of loading the fuel assemblies into the canister. The potential error modeled is improper loading by placing a fuel assembly into a wrong location in the canister. A loading map is provided to the crew. The map indicates specific spent fuel assemblies by serial number and the specific placement location of each in the canister. The fuel crane operator selects, moves, and places each assembly into the cask using a video image at his workstation on the crane from an underwater camera attached to the cranes' grapple assembly. Each fuel assembly's serial number is stamped onto the top of the assembly. Worksheet ratings that are other than nominal are "moderate complexity" and "poor" ergonomics for both the diagnosis and action component of the task. Note that the worksheets do not account for latent errors related to the production of the fuel-loading map.

The second example is the SPAR-H worksheet for the operators failing to properly remove water from the canister by stepped vacuuming during the drying and inserting process. This activity takes place after the cask has been removed from the fuel pool and the canister has been sealed. The diagnosis component and action component of the activity each include a worksheet rating of "moderate complexity." The diagnosis component complexity rating considers the required calculation of the maximum time allowed for wet operations (e.g., allowable time from removal from fuel pool to when the canister drying is completed). Both the diagnosis and the action component complexity ratings reflect requirements for multiple valve line-ups, multiple timings for stepped drying, and continuous monitoring and multiple recordings of canister pressure during drying to allow determination of drying acceptance criteria.

The third example is the SPAR-H worksheet for operators failing to properly perform vacuum drying system connections and set-up to enable drying of the cask annulus during the close cask phase of the operation. The worksheet rating of complexity is "moderate complexity" for both the diagnosis and action components of the activity. This reflects the multiple steps, components, connections, and manipulations required. The rating for procedures is "available, but poor" for both the diagnosis and action components of the activity. This rating reflects that the procedure refers to an attachment showing connections for the canister rather than the cask (which employs different valve connections), and that the attachment has inconsistent or missing symbols.

HRA Worksheets for LP/SD

SPAR Human Error Worksheet

Plant: Plant X Initiating Event: Fuel Overload Basic Event : XHE Event Coder: bf

Basic Event Context: Fuel Overloading Resulting in Higher Surface Radiation than Allowable

Basic Event Description: Failure to Load Fuel Assemblies Properly

Does this task contain a significant amount of diagnosis activity? YES ☒ (start with Part I–Diagnosis) NO ☐ (skip Part I – Diagnosis; start with Part II – Action) Why? **Multiple assemblies/serial numbers/specific placement locations/verifications.**

PART I. EVALUATE EACH PSF FOR DIAGNOSIS

A. Evaluate PSFs for the Diagnosis Portion of the Task.

PSFs	PSF Levels	Multiplier for Diagnosis		Please note specific reasons for PSF level selection in this column.
Available Time	Inadequate time	P(failure) = 1.0	☐	Adequate (nominal) time is assumed in this example.
	Barely adequate time (≈ 2/3 x nominal)	10	☐	
	Nominal time	1	☒	
	Extra time (between 1and 2 x nominal and > 30 min)	0.1	☐	
	Expansive time > 2 x nominal & > 30 min	0.1 to 0.01	☐	
	Insufficient Information	1	☐	
Stress/ Stressors	Extreme	5	☐	There is no information available on stress in this example.
	High	2	☐	
	Nominal	1	☐	
	Insufficient Information	1	☒	
Complexity	Highly complex	5	☐	Multiple fuel assemblies, serial numbers stamped on the top of each assembly, specific placement locations in the canister.
	Moderately complex	2	☒	
	Nominal	1	☐	
	Obvious diagnosis	0.1	☐	
	Insufficient Information	1	☐	
Experience/ Training	Low	10	☐	Average (nominal) experience and training are assumed in this example.
	Nominal	1	☒	
	High	0.5	☐	
	Insufficient Information	1	☐	
Procedures	Not available	50	☐	Procedures are plant specific. This analysis was determined from a generic model and therefore nominal is an appropriate choice.
	Incomplete	20	☐	
	Available, but poor	5	☐	
	Nominal	1	☒	
	Diagnostic/symptom oriented	0.5	☐	
	Insufficient Information	1	☐	
Ergonomics/ HMI	Missing/Misleading	50	☐	Performed by remote control underwater using video camera view. (Assembly selection, placement, and verification.)
	Poor	10	☒	
	Nominal	1	☐	
	Good	0.5	☐	
	Insufficient Information	1	☐	
Fitness for Duty	Unfit	P(failure) = 1.0	☐	The fitness for duty of the crew is plant and crew specific. This analysis was determined from a generic model and therefore nominal is an appropriate choice.
	Degraded Fitness	5	☐	
	Nominal	1	☒	
	Insufficient Information	1	☐	
Work Processes	Poor	2	☐	The work processes are plant and crew specific. This analysis was determined from a generic model and therefore nominal is an appropriate choice.
	Nominal	1	☒	
	Good	0.8	☐	
	Insufficient Information	1	☐	

Rev 1 (1/20/04)

Reviewer: aw

Plant: Plant X Initiating Event: Fuel Overload Basic Event : XHE Event Coder: bf

Basic Event Context: Fuel Overloading Resulting in Higher Surface Radiation than Allowable

Basic Event Description: Failure to Load Fuel Assemblies Properly

B. Calculate the Diagnosis Failure Probability.

(1) If all PSF ratings are nominal, then the Diagnosis Failure Probability = 1.0E-2
(2) Otherwise, the Diagnosis Failure Probability is: 1.0E-2 x Time x Stress or Stressors x Complexity x Experience or Training x Procedures x Ergonomics or HMI x Fitness for Duty x Processes

Diagnosis: 1.0E-2x **1** x **1** x **2** x **1** x **1** x **10** x **1** x **1** = **0.2**

C. Calculate the Adjustment Factor IF Negative Multiple (≥3) PSFs are Present.

When 3 or more negative PSF influences are present, in lieu of the equation above, you must compute a composite PSF score used in conjunction with the adjustment factor. Negative PSFs are present anytime a multiplier greater than 1 is selected. The Nominal HEP (NHEP) is 1.0E-2 for Diagnosis. The composite PSF score is computed by multiplying all the assigned PSF values. Then the adjustment factor below is applied to compute the HEP:

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

Diagnosis HEP with Adjustment Factor = **N/A**

D. Record Final Diagnosis HEP.

If no adjustment factor was applied, record the value from Part B as your final diagnosis HEP. If an adjustment factor was applied, record the value from Part C.

Final Diagnosis HEP = **0.2**

Reviewer: aw

Plant: Plant X Initiating Event: Fuel Overload Basic Event : XHE Event Coder: bf

Basic Event Context: Fuel Overloading Resulting in Higher Surface Radiation than Allowable

Basic Event Description: Failure to Load Fuel Assemblies Properly

Part II. EVALUATE EACH PSF FOR ACTION

A. Evaluate PSFs for the Action Portion of the Task, If Any.

PSFs	PSF Levels	Multiplier for Action		Please note specific reasons for PSF level selection in this column.
Available Time	Inadequate time	P(failure) = 1.0	☐	Adequate (nominal) time is assumed in this example.
	Time available is ≈ the time required	10	☐	
	Nominal time	1	☒	
	Time available ≥ 5x the time required	0.1	☐	
	Time available is ≥ 50x the time required	0.01	☐	
	Insufficient Information	1	☐	
Stress/ Stressors	Extreme	5	☐	There is no information available on stress in this example.
	High	2	☐	
	Nominal	1	☐	
	Insufficient Information	1	☒	
Complexity	Highly complex	5	☐	Multiple assemblies with specific placements in canister.
	Moderately complex	2	☒	
	Nominal	1	☐	
	Insufficient Information	1	☐	
Experience/ Training	Low	3	☐	Average (nominal) experience and training are assumed in this example.
	Nominal	1	☒	
	High	0.5	☐	
	Insufficient Information	1	☐	
Procedures	Not available	50	☐	Procedures are plant specific. This analysis was determined from a generic model and therefore nominal is an appropriate choice.
	Incomplete	20	☐	
	Available, but poor	5	☐	
	Nominal	1	☒	
	Insufficient Information	1	☐	
Ergonomics/ HMI	Missing/Misleading	50	☐	Performed by remote control underwater using video camera view. (Assembly selections, placement, and verification serial number stamps with underwater camera.)
	Poor	10	☒	
	Nominal	1	☐	
	Good	0.5	☐	
	Insufficient Information	1	☐	
Fitness for Duty	Unfit	P(failure) = 1.0	☐	The fitness for duty of the crew is plant and crew specific. This analysis was determined from a generic model and therefore nominal is an appropriate choice.
	Degraded Fitness	5	☐	
	Nominal	1	☒	
	Insufficient Information	1	☐	
Work Processes	Poor	5	☐	The work processes are plant and crew specific. This analysis was determined from a generic model and therefore nominal is an appropriate choice.
	Nominal	1	☒	
	Good	0.5	☐	
	Insufficient Information	1	☐	

Reviewer: aw

Plant: Plant X Initiating Event: Fuel Overload Basic Event : XHE Event Coder: bf

Basic Event Context: Fuel Overloading Resulting in Higher Surface Radiation than Allowable

Basic Event Description: Failure to Load Fuel Assemblies Properly

B. Calculate the Action Failure Probability.

(1) If all PSF ratings are nominal, then the Action Failure Probability = 1.0E-3
(2) Otherwise, the Action Failure Probability is: 1.0E-3 x Time x Stress or Stressors x Complexity x Experience or Training x Procedures x Ergonomics or HMI x Fitness for Duty x Processes

Action: 1.0E-3x **1** x **1** x **2** x **1** x **1** x **10** x **1** x **1** = **0.02**

C. Calculate the Adjustment Factor IF Negative Multiple (≥3) PSFs are Present.

When 3 or more negative PSF influences are present, in lieu of the equation above, you must compute a composite PSF score used in conjunction with the adjustment factor. Negative PSFs are present anytime a multiplier greater than 1 is selected. The Nominal HEP (NHEP) is 1.0E-3 for Action. The composite PSF score is computed by multiplying all the assigned PSF values. Then the adjustment factor below is applied to compute the HEP:

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

Action HEP with Adjustment Factor = **N/A**

D. Record Final Action HEP.

If no adjustment factor was applied, record the value from Part B as your final action HEP. If an adjustment factor was applied, record the value from Part C.

Final Action HEP = **0.02**

Reviewer: aw

Plant: Plant X Initiating Event: Fuel Overload Basic Event : XHE_____ Event Coder: _bf________

Basic Event Context: Fuel Overloading Resulting in Higher Surface Radiation than Allowable

Basic Event Description: Failure to Load Fuel Assemblies Properly

PART III. CALCULATE TASK FAILURE PROBABILITY WITHOUT FORMAL DEPENDENCE ($P_{W/OD}$)

Calculate the Task Failure Probability Without Formal Dependence ($P_{w/od}$) by adding the Diagnosis Failure Probability from Part I and the Action Failure Probability from Part II. In instances where an action is required without a diagnosis and there is no dependency, then this step is omitted.

$P_{w/od}$ = Diagnosis HEP __**0.2**____ + Action HEP ___**0.22**___ = **0.22**

Part IV. DEPENDENCY

For all tasks, except the first task in the sequence, use the table and formulae below to calculate the Task Failure Probability With Formal Dependence ($P_{w/d}$).

If there is a reason why failure on previous tasks should not be considered, such as it is impossible to take the current action unless the previous action has been properly performed, explain here: **First event in sequence.**

Dependency Condition Table

Condition Number	Crew (same or different)	Time (close in time or not close in time)	Location (same or different)	Cues (additional or no additional)	Dependency	Number of Human Action Failures Rule ☐ - Not Applicable. Why?_________________
1	s	c	s	na	complete	When considering recovery in a series e.g., 2nd, 3rd, or 4th checker
2				a	complete	
3			d	na	high	If this error is the **3rd error in the sequence**, then the dependency is at least **moderate**.
4				a	high	
5		nc	s	na	high	
6				a	moderate	
7			d	na	moderate	If this error is the **4th error in the sequence**, then the dependency is at least **high.**
8				a	low	
9	d	c	s	na	moderate	
10				a	moderate	
11			d	na	moderate	
12				a	moderate	
13		nc	s	na	low	
14				a	low	
15			d	na	low	
16				a	low	
17					zero ✔	

Using $P_{w/od}$ = Probability of Task Failure Without Formal Dependence (calculated in Part III):

For Complete Dependence the probability of failure is 1.
For High Dependence the probability of failure is $(1+ P_{w/od})/2$
For Moderate Dependence the probability of failure is $(1+6 \times P_{w/od})/7$
For Low Dependence the probability of failure is $(1+19 \times P_{w/od})/20$
For Zero Dependence the probability of failure is $P_{w/od}$ ✔

Calculate $P_{w/d}$ using the appropriate values:

$P_{w/d}$ = (1 + (_______ * _______))/ _______ = **N/A**

Reviewer: _aw_________

HRA Worksheets for LP/SD

SPAR Human Error Worksheet

Plant: Plant X Initiating Event: Excess Water Criticality Basic Event : XHE Event Coder: bf

Basic Event Context: Dry and Insert the Canister

Basic Event Description: Operators Fail to Remove Water Properly by Stepped Vacuuming

Does this task contain a significant amount of diagnosis activity? YES ☒ (start with Part I–Diagnosis) NO ☐ (skip Part I – Diagnosis; start with Part II – Action) Why? **Maximum time calculation, timings, monitorings, recordings.**

PART I. EVALUATE EACH PSF FOR DIAGNOSIS

A. Evaluate PSFs for the Diagnosis Portion of the Task.

PSFs	PSF Levels	Multiplier for Diagnosis	Please note specific reasons for PSF level selection in this column.
Available Time	Inadequate time	P(failure) = 1.0 ☐	Adequate (nominal) time is assumed in this example.
	Barely adequate time (≈ 2/3 x nominal)	10 ☐	
	Nominal time	1 ☒	
	Extra time (between 1and 2 x nominal and > 30 min)	0.1 ☐	
	Expansive time > 2 x nominal & > 30 min	0.1 to 0.01 ☐	
	Insufficient Information	1 ☐	
Stress/ Stressors	Extreme	5 ☐	There is no information available on stress in this example.
	High	2 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☒	
Complexity	Highly complex	5 ☐	Maximum time calculations, multiple valve lineups, timings, and monitoring.
	Moderately complex	2 ☒	
	Nominal	1 ☐	
	Obvious diagnosis	0.1 ☐	
	Insufficient Information	1 ☐	
Experience/ Training	Low	10 ☐	Average (nominal) experience and training are assumed in this example.
	Nominal	1 ☒	
	High	0.5 ☐	
	Insufficient Information	1 ☐	
Procedures	Not available	50 ☐	Procedures are plant specific. This analysis was determined from a generic model and therefore nominal is an appropriate choice.
	Incomplete	20 ☐	
	Available, but poor	5 ☐	
	Nominal	1 ☒	
	Diagnostic/symptom oriented	0.5 ☐	
	Insufficient Information	1 ☐	
Ergonomics/ HMI	Missing/Misleading	50 ☐	The ergonomics are improved for this task compared to previous task, such that there are no indicators that ergonomics would significantly contribute to human error.
	Poor	10 ☐	
	Nominal	1 ☒	
	Good	0.5 ☐	
	Insufficient Information	1 ☐	
Fitness for Duty	Unfit	P(failure) = 1.0 ☐	The fitness for duty of the crew is plant and crew specific. This analysis was determined from a generic model and therefore nominal is an appropriate choice.
	Degraded Fitness	5 ☐	
	Nominal	1 ☒	
	Insufficient Information	1 ☐	
Work Processes	Poor	2 ☐	The work processes are plant and crew specific. This analysis was determined from a generic model and therefore nominal is an appropriate choice.
	Nominal	1 ☒	
	Good	0.8 ☐	
	Insufficient Information	1 ☐	

Rev 1 (1/20/04)

Reviewer: aw

Plant: Plant X Initiating Event: Excess Water Criticality Basic Event : XHE Event Coder: bf

Basic Event Context: Dry and Insert the Canister

Basic Event Description: Operators Fail to Remove Water Properly by Stepped Vacuuming

B. Calculate the Diagnosis Failure Probability.

(1) If all PSF ratings are nominal, then the Diagnosis Failure Probability = 1.0E-2
(2) Otherwise, the Diagnosis Failure Probability is: 1.0E-2 x Time x Stress or Stressors x Complexity x Experience or Training x Procedures x Ergonomics or HMI x Fitness for Duty x Processes

Diagnosis: 1.0E-2x **1** x **1** x **2** x **1** x **1** x **1** x **1** x **1** = **0.02**

C. Calculate the Adjustment Factor IF Negative Multiple (≥3) PSFs are Present.

When 3 or more negative PSF influences are present, in lieu of the equation above, you must compute a composite PSF score used in conjunction with the adjustment factor. Negative PSFs are present anytime a multiplier greater than 1 is selected. The Nominal HEP (NHEP) is 1.0E-2 for Diagnosis. The composite PSF score is computed by multiplying all the assigned PSF values. Then the adjustment factor below is applied to compute the HEP:

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

Diagnosis HEP with Adjustment Factor = **N/A**

D. Record Final Diagnosis HEP.

If no adjustment factor was applied, record the value from Part B as your final diagnosis HEP. If an adjustment factor was applied, record the value from Part C.

Final Diagnosis HEP = **0.02**

Reviewer: aw

Plant: Plant X Initiating Event: Excess Water Criticality Basic Event : XHE__ Event Coder:_bf__

Basic Event Context: Dry and Insert the Canister

Basic Event Description: Operators Fail to Remove Water Properly by Stepped Vacuuming

Part II. EVALUATE EACH PSF FOR ACTION

A. Evaluate PSFs for the Action Portion of the Task, If Any.

PSFs	PSF Levels	Multiplier for Action		Please note specific reasons for PSF level selection in this column.
Available Time	Inadequate time	P(failure) = 1.0	☐	Adequate (nominal) time is assumed in this example.
	Time available is ≈ the time required	10	☐	
	Nominal time	1	☒	
	Time available ≥ 5x the time required	0.1	☐	
	Time available is ≥ 50x the time required	0.01	☐	
	Insufficient Information	1	☐	
Stress/ Stressors	Extreme	5	☐	There is no information available on stress in this example.
	High	2	☐	
	Nominal	1	☐	
	Insufficient Information	1	☒	
Complexity	Highly complex	5	☐	Maximum time calculations, multiple valve lineups, timings, and monitoring.
	Moderately complex	2	☒	
	Nominal	1	☐	
	Insufficient Information	1	☐	
Experience/ Training	Low	3	☐	Average (nominal) experience and training are assumed in this example.
	Nominal	1	☒	
	High	0.5	☐	
	Insufficient Information	1	☐	
Procedures	Not available	50	☐	Procedures are plant specific. This analysis was determined from a generic model and therefore nominal is an appropriate choice.
	Incomplete	20	☐	
	Available, but poor	5	☐	
	Nominal	1	☒	
	Insufficient Information	1	☐	
Ergonomics/ HMI	Missing/Misleading	50	☐	The ergonomics are improved for this task compared to previous task, such that there are no indicators that ergonomics would significantly contribute to human error.
	Poor	10	☐	
	Nominal	1	☒	
	Good	0.5	☐	
	Insufficient Information	1	☐	
Fitness for Duty	Unfit	P(failure) = 1.0	☐	The fitness for duty of the crew is plant and crew specific. This analysis was determined from a generic model and therefore nominal is an appropriate choice.
	Degraded Fitness	5	☐	
	Nominal	1	☒	
	Insufficient Information	1	☐	
Work Processes	Poor	5	☐	The work processes are plant and crew specific. This analysis was determined from a generic model and therefore nominal is an appropriate choice.
	Nominal	1	☒	
	Good	0.5	☐	
	Insufficient Information	1	☐	

Reviewer: aw

Plant: Plant X Initiating Event: Excess Water Criticality Basic Event : XHE Event Coder: bf

Basic Event Context: Dry and Insert the Canister

Basic Event Description: Operators Fail to Remove Water Properly by Stepped Vacuuming

B. Calculate the Action Failure Probability.

(1) If all PSF ratings are nominal, then the Action Failure Probability = 1.0E-3
(2) Otherwise, the Action Failure Probability is: 1.0E-3 x Time x Stress or Stressors x Complexity x Experience or Training x Procedures x Ergonomics or HMI x Fitness for Duty x Processes

Action: 1.0E-3x **1** x **1** x **2** x **1** x **1** x **1** x **1** x **1** = **0.002**

C. Calculate the Adjustment Factor IF Negative Multiple (≥3) PSFs are Present.

When 3 or more negative PSF influences are present, in lieu of the equation above, you must compute a composite PSF score used in conjunction with the adjustment factor. Negative PSFs are present anytime a multiplier greater than 1 is selected. The Nominal HEP (NHEP) is 1.0E-3 for Action. The composite PSF score is computed by multiplying all the assigned PSF values. Then the adjustment factor below is applied to compute the HEP:

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

Action HEP with Adjustment Factor = **N/A**

D. Record Final Action HEP.

If no adjustment factor was applied, record the value from Part B as your final action HEP. If an adjustment factor was applied, record the value from Part C.

Final Action HEP = **0.002**

Reviewer: aw

Plant: Plant X Initiating Event: Excess Water Criticality Basic Event : XHE__ Event Coder: bf__

Basic Event Context: Dry and Insert the Canister

Basic Event Description: Operators Fail to Remove Water Properly by Stepped Vacuuming

PART III. CALCULATE TASK FAILURE PROBABILITY WITHOUT FORMAL DEPENDENCE ($P_{W/OD}$)

Calculate the Task Failure Probability Without Formal Dependence ($P_{w/od}$) by adding the Diagnosis Failure Probability from Part I and the Action Failure Probability from Part II. In instances where an action is required without a diagnosis and there is no dependency, then this step is omitted.

$P_{w/od}$ = Diagnosis HEP __**0.02**__ + Action HEP __**0.002**__ = **0.022**

Part IV. DEPENDENCY

For all tasks, except the first task in the sequence, use the table and formulae below to calculate the Task Failure Probability With Formal Dependence ($P_{w/d}$).

If there is a reason why failure on previous tasks should not be considered, such as it is impossible to take the current action unless the previous action has been properly performed, explain here: **Not the same crew, time, location, and cues as previous event.**

Dependency Condition Table

Condition Number	Crew (same or different)	Time (close in time or not close in time)	Location (same or different)	Cues (additional or no additional)	Dependency	Number of Human Action Failures Rule ☐ - Not Applicable. Why?________________
1	s	c	s	na	complete	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.**
2				a	complete	
3			d	na	high	
4				a	high	
5		nc	s	na	high	
6				a	moderate	
7			d	na	moderate	
8				a	low	
9	d	c	s	na	moderate	
10				a	moderate	
11			d	na	moderate	
12				a	moderate	
13		nc	s	na	low	
14				a	low	
15			d	na	low	
16				a	low ✔	
17					zero	

Using $P_{w/od}$ = Probability of Task Failure Without Formal Dependence (calculated in Part III):

For Complete Dependence the probability of failure is 1.
For High Dependence the probability of failure is $(1+ P_{w/od})/2$
For Moderate Dependence the probability of failure is $(1+6 \times P_{w/od})/7$
For Low Dependence the probability of failure is $(1+19 \times P_{w/od})/20$ ✔
For Zero Dependence the probability of failure is $P_{w/od}$

Calculate $P_{w/d}$ using the appropriate values:

$P_{w/d}$ = (1 + (__**19**__ * __**0.022**__))/ __**20**__ = **0.0709**

Reviewer: aw

HRA Worksheets for LP/SD

SPAR Human Error Worksheet

Plant: Plant X Initiating Event: Excess Water Criticality Basic Event : XHE Event Coder: bf

Basic Event Context: Cask Closure

Basic Event Description: Operators Fail to Perform Vacuum Drying System Connections/Setup

Does this task contain a significant amount of diagnosis activity? YES ☒ (start with Part I–Diagnosis) NO ☐ (skip Part I – Diagnosis; start with Part II – Action) Why? **Multiple steps, components, connections, and manipulations.**

PART I. EVALUATE EACH PSF FOR DIAGNOSIS

A. Evaluate PSFs for the Diagnosis Portion of the Task.

PSFs	PSF Levels	Multiplier for Diagnosis	Please note specific reasons for PSF level selection in this column.
Available Time	Inadequate time	P(failure) = 1.0 ☐	Adequate (nominal) time is assumed in this example.
	Barely adequate time (≈ 2/3 x nominal)	10 ☐	
	Nominal time	1 ☒	
	Extra time (between 1and 2 x nominal and > 30 min)	0.1 ☐	
	Expansive time > 2 x nominal & > 30 min	0.1 to 0.01 ☐	
	Insufficient Information	1 ☐	
Stress/ Stressors	Extreme	5 ☐	There is no information available on stress in this example.
	High	2 ☐	
	Nominal	1 ☐	
	Insufficient Information	1 ☒	
Complexity	Highly complex	5 ☐	Multiple steps, components, connections, and manipulations.
	Moderately complex	2 ☒	
	Nominal	1 ☐	
	Obvious diagnosis	0.1 ☐	
	Insufficient Information	1 ☐	
Experience/ Training	Low	10 ☐	Average (nominal) experience and training are assumed in this example.
	Nominal	1 ☒	
	High	0.5 ☐	
	Insufficient Information	1 ☐	
Procedures	Not available	50 ☐	Attachment refers to canister rather than cask, which employs different valve connections and contains inconsistent or missing symbols.
	Incomplete	20 ☐	
	Available, but poor	5 ☒	
	Nominal	1 ☐	
	Diagnostic/symptom oriented	0.5 ☐	
	Insufficient Information	1 ☐	
Ergonomics/ HMI	Missing/Misleading	50 ☐	There are no indications that ergonomics would significantly contribute to human error for this task.
	Poor	10 ☐	
	Nominal	1 ☒	
	Good	0.5 ☐	
	Insufficient Information	1 ☐	
Fitness for Duty	Unfit	P(failure) = 1.0 ☐	The fitness for duty of the crew is plant and crew specific. This analysis was determined from a generic model and therefore nominal is an appropriate choice.
	Degraded Fitness	5 ☐	
	Nominal	1 ☒	
	Insufficient Information	1 ☐	
Work Processes	Poor	2 ☐	The work processes are plant and crew specific. This analysis was determined from a generic model and therefore nominal is an appropriate choice.
	Nominal	1 ☒	
	Good	0.8 ☐	
	Insufficient Information	1 ☐	

Rev 1 (1/20/04)

Reviewer: aw

Plant: Plant X Initiating Event: Excess Water Criticality Basic Event : XHE Event Coder: bf

Basic Event Context: Cask Closure

Basic Event Description: Operators Fail to Perform Vacuum Drying System Connections/Setup

B. Calculate the Diagnosis Failure Probability.

(1) If all PSF ratings are nominal, then the Diagnosis Failure Probability = 1.0E-2
(2) Otherwise, the Diagnosis Failure Probability is: 1.0E-2 x Time x Stress or Stressors x Complexity x Experience or Training x Procedures x Ergonomics or HMI x Fitness for Duty x Processes

Diagnosis: 1.0E-2x **1** x **1** x **2** x **1** x **5** x **1** x **1** x **1** = **0.1**

C. Calculate the Adjustment Factor IF Negative Multiple (≥3) PSFs are Present.

When 3 or more negative PSF influences are present, in lieu of the equation above, you must compute a composite PSF score used in conjunction with the adjustment factor. Negative PSFs are present anytime a multiplier greater than 1 is selected. The Nominal HEP (NHEP) is 1.0E-2 for Diagnosis. The composite PSF score is computed by multiplying all the assigned PSF values. Then the adjustment factor below is applied to compute the HEP:

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

Diagnosis HEP with Adjustment Factor = **N/A**

D. Record Final Diagnosis HEP.

If no adjustment factor was applied, record the value from Part B as your final diagnosis HEP. If an adjustment factor was applied, record the value from Part C.

Final Diagnosis HEP = **0.1**

Reviewer: aw

Plant: Plant X Initiating Event: Excess Water Criticality Basic Event : XHE Event Coder: bf

Basic Event Context: Cask Closure

Basic Event Description: Operators Fail to Perform Vacuum Drying System Connections/Setup

Part II. EVALUATE EACH PSF FOR ACTION

A. Evaluate PSFs for the Action Portion of the Task, If Any.

PSFs	PSF Levels	Multiplier for Action		Please note specific reasons for PSF level selection in this column.
Available Time	Inadequate time	P(failure) = 1.0	☐	Adequate (nominal) time is assumed in this example.
	Time available is ≈ the time required	10	☐	
	Nominal time	1	☒	
	Time available ≥ 5x the time required	0.1	☐	
	Time available is ≥ 50x the time required	0.01	☐	
	Insufficient Information	1	☐	
Stress/ Stressors	Extreme	5	☐	There is no information available on stress in this example.
	High	2	☐	
	Nominal	1	☐	
	Insufficient Information	1	☒	
Complexity	Highly complex	5	☐	Observers of this task suggest moderate complexity for operators.
	Moderately complex	2	☒	
	Nominal	1	☐	
	Insufficient Information	1	☐	
Experience/ Training	Low	3	☐	Average (nominal) experience and training are assumed in this example.
	Nominal	1	☒	
	High	0.5	☐	
	Insufficient Information	1	☐	
Procedures	Not available	50	☐	Attachment refers to canister rather than cask, which employs different valve connections and contains inconsistent or missing symbols.
	Incomplete	20	☐	
	Available, but poor	5	☒	
	Nominal	1	☐	
	Insufficient Information	1	☐	
Ergonomics/ HMI	Missing/Misleading	50	☐	There are no indications that ergonomics would significantly contribute to human error for this task.
	Poor	10	☐	
	Nominal	1	☒	
	Good	0.5	☐	
	Insufficient Information	1	☐	
Fitness for Duty	Unfit	P(failure) = 1.0	☐	The fitness for duty of the crew is plant and crew specific. This analysis was determined from a generic model and therefore nominal is an appropriate choice.
	Degraded Fitness	5	☐	
	Nominal	1	☒	
	Insufficient Information	1	☐	
Work Processes	Poor	5	☐	The work processes are plant and crew specific. This analysis was determined from a generic model and therefore nominal is an appropriate choice.
	Nominal	1	☒	
	Good	0.5	☐	
	Insufficient Information	1	☐	

Reviewer: aw

Plant: Plant X Initiating Event: Excess Water Criticality Basic Event : XHE Event Coder: bf

Basic Event Context: Cask Closure

Basic Event Description: Operators Fail to Perform Vacuum Drying System Connections/Setup

B. Calculate the Action Failure Probability.

(1) If all PSF ratings are nominal, then the Action Failure Probability = 1.0E-3
(2) Otherwise, the Action Failure Probability is: 1.0E-3 x Time x Stress or Stressors x Complexity x Experience or Training x Procedures x Ergonomics or HMI x Fitness for Duty x Processes

Action: 1.0E-3x **1** x **1** x **2** x **1** x **1** x **5** x **1** x **1** = **0.01**

C. Calculate the Adjustment Factor IF Negative Multiple (≥3) PSFs are Present.

When 3 or more negative PSF influences are present, in lieu of the equation above, you must compute a composite PSF score used in conjunction with the adjustment factor. Negative PSFs are present anytime a multiplier greater than 1 is selected. The Nominal HEP (NHEP) is 1.0E-3 for Action. The composite PSF score is computed by multiplying all the assigned PSF values. Then the adjustment factor below is applied to compute the HEP:

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

Action HEP with Adjustment Factor = **N/A**

D. Record Final Action HEP.

If no adjustment factor was applied, record the value from Part B as your final action HEP. If an adjustment factor was applied, record the value from Part C.

Final Action HEP = **0.01**

Reviewer: aw

Plant: Plant X Initiating Event: Excess Water Criticality Basic Event : XHE Event Coder: bf

Basic Event Context: Cask Closure

Basic Event Description: Operators Fail to Perform Vacuum Drying System Connections/Setup

PART III. CALCULATE TASK FAILURE PROBABILITY WITHOUT FORMAL DEPENDENCE ($P_{W/OD}$)

Calculate the Task Failure Probability Without Formal Dependence ($P_{w/od}$) by adding the Diagnosis Failure Probability from Part I and the Action Failure Probability from Part II. In instances where an action is required without a diagnosis and there is no dependency, then this step is omitted.

$P_{w/od}$ = Diagnosis HEP **0.1** + Action HEP **0.01** = **0.11**

Part IV. DEPENDENCY

For all tasks, except the first task in the sequence, use the table and formulae below to calculate the Task Failure Probability With Formal Dependence ($P_{w/d}$).

If there is a reason why failure on previous tasks should not be considered, such as it is impossible to take the current action unless the previous action has been properly performed, explain here: **Not the same crew, time, location, and cues as previous event.**

Dependency Condition Table

Condition Number	Crew (same or different)	Time (close in time or not close in time)	Location (same or different)	Cues (additional or no additional)	Dependency	Number of Human Action Failures Rule ☐ - Not Applicable. Why?_________________
1	s	c	s	na	complete	When considering recovery in a series e.g., 2nd, 3rd, or 4th checker
2				a	complete	
3			d	na	high	If this error is the **3rd error in the sequence**, then the dependency is at least **moderate**.
4				a	high	
5		nc	s	na	high	
6				a	moderate	
7			d	na	moderate	If this error is the **4th error in the sequence**, then the dependency is at least **high.**
8				a	low	
9	d	c	s	na	moderate	
10				a	moderate	
11			d	na	moderate	Note that this is the 3 rd error in the sequence and defaults to moderate dependency.
12				a	moderate	
13		nc	s	na	low	
14				a	low	
15			d	na	low	
16				a	low ✔	
17					zero	

Using $P_{w/od}$ = Probability of Task Failure Without Formal Dependence (calculated in Part III):

For Complete Dependence the probability of failure is 1.
For High Dependence the probability of failure is $(1+ P_{w/od})/2$
For Moderate Dependence the probability of failure is $(1+6 \times P_{w/od})/7$ ✔
For Low Dependence the probability of failure is $(1+19 \times P_{w/od})/20$
For Zero Dependence the probability of failure is $P_{w/od}$

Calculate $P_{w/d}$ using the appropriate values:

$P_{w/d}$ = (1 + (**6** * **0.11**))/ **7** = **0.2371**

Reviewer: aw

Appendix F

Operational Examples of SPAR-H Method Assignment of PSF Levels

Appendix F
Operational Examples of SPAR-H Method Assignment of PSF Levels

Available Time – Time available ≈ time required

Event ID (Plant / Date / Report Type)	Event Summary	PSF Description
HNP1 06/27/93 AIT	3 events occurred (06/22-06/27) while conducting tests. 6/22 & 6/26: total loss of offsite power from wiring error & blown fuse respectively. 6/27: temporary loss of motor-control-center-5, which provides power to ECCS. Erroneous alert changed to unusual.	Shift supervisor felt he was under time pressure to process the notification within the 12 minutes required by the procedure (takes 10 minutes to input the data) and did so at the expense of assuring information accuracy.

Stress/Stressors – High

Event ID (Plant / Date / Report Type)	Event Summary	PSF Description
ZIS1 02/21/97 AIT	Following 48 hr limiting condition of operation (LCO) and 4 hr Technical Specification (TS) shutdown statement, Nuclear Station Operator (NSO) initiates improper control rod manipulations during unit 1 shutdown, inserts rods for 3'43", then rods withdrawn for 1'45" without estimated critical position calculation while reactor (RX) substantially subcritical. RX tripped for containment sump (CS) pump problem prior to criticality. Inadequate reactivity management.	39 people in control room envelope with 15 people in immediate vicinity of the primary NSO operating rods and the US, high ambient noise level, attempts to restore the 1CS pump was the most intrusive activity during the event.
NMP2 08/13/91 IIT	Internal failure in main transformer caused turbine trip and RX scram. Degraded voltage resulted in simultaneous common-mode loss of 5 uninterruptible power supplies to important control room instrumentation and other plant equipment. Brought to safe shutdown	Stress and time pressure were high. Event occurred just before shift change. Operators had confidence in their training.
NAS2 04/16/93 HPS	Control problem in main generator voltage regulator led to overexcited condition and reactor trip. Auxiliary feedwater(AFW) pumps disabled for eighteen minutes during reactor trip recovery.	Stress due to unfamiliar crew composition. Sense of less communication/feedback than usual. Operator broke glass cover on control board indicator. Feeling of urgency.
EFP2 08/13/93 HPS	Spurious reactor scram, loss of gland seal steam and condenser vacuum resulted in main steam isolation valve (MSIV) closure and steam relief valve (SRV) pressure control.	Numerous failures and the smell of smoke during the initial stages of recovery diverted or consumed operator attention. Stress from unexpected alarms, trips, uncertainty of cause, and the first RX trip at high power for the crew.

Complexity – Moderately complex

Event ID (Plant / Date / Report Type)	Event Summary	PSF Description
NEE3 07/03/91 ASPLER	Operator left demineralizer bypass valves shut in manual. Later, instrument air to condensate demineralizer valve controller became blocked. All automatic valves shut, bypass could not respond. Condensate booster pumps tripped. Main feed pumps tripped. Reactor tripped.	Control room operator (CRO) was performing multiple, concurrent tasks. Operator was interrupted by phone call related to second task and forgot to place the bypass valve control in AUTO status after interruption.

Experience/Training – Low

Event ID (Plant/Date / Report Type)	Event Summary	PSF Description
DCC1 09/12/95 ASPLER	In Mode 6 and defueled, West Centrifugal Charging Pump (CPP) tripped after 7 min. of a surveillance test. Pump had tripped due to incorrect setting for overcurrent relay. Later determined pump had been inoperable for 6 mo., since last calibration. Personnel had used wrong technique resulting in miscalibration.	Root cause was lack of requalification training, which resulted in the calibration error made by the technicians. Although adequately trained initially, a significant amount of time had elapsed since training and a lack of requalification training led to the personnel error.
MGS1 06/26/90 ASPLER	Diesel generator 1A failed to reach required voltage in required time during operability test. Subsequent start attempt resulted in valid failure due to unsuccessful loading attempt. Paint overspray was found on the commutator ring and fuel racks of diesel generator (DG) 1A and 1B. Both DGs were declared inoperable. Paint removed from D/Gs and operability tests were successful.	Root cause of inappropriate action by maintenance personnel of painting area above fuel racks was unauthorized; maintenance personnel relied on their own experience as to what to paint. Also Operations support person in charge of D/Gs believed (wrongly) specific guidance about what to paint was not necessary because the same personnel had previously painted the Unit 2 D/Gs.
BRF2 05/11/93 HPS	Isolation of valve associated with indicator used to monitor & control pressure resulted in actions causing high pressure in reactor coolant system (RCS) & an ARI/RPT engineered safety features (ESF) actuation during test	No training: crew had little experience with the tests because they were performed infrequently. No simulator training on test.
WGS3 06/10/95 AIT	RX trip resulted from offsite electrical disturbance (lightning arrester failure). Fire in turbine building switchgear room resulted from auto load transfer problems. Shutdown cooling delayed by failure of isolation valves for both shutdown cooling trains.	Inadequate training of operators to respond to initial indications of potentially significant fire. Fire brigade training weakness resulted in reluctance to use water to extinguish fire when other fire suppression methods failed.

Event ID (Plant/Date / Report Type)	Event Summary	PSF Description
PAV3 05/04/92 AIT	Loss of non-safety related annunciator and computer alarm systems following a circuit breaker trip alarm verification that created an inadvertent short circuit.	Not provided for loss of all non-safety related annunciators during normal or abnormal operating conditions because of perceived low probability of such an event.
EFP2 08/13/93 HPS	Spurious reactor scram, loss of gland seal steam and condenser vacuum resulted in MSIV closure and SRV pressure control.	No training: simulator training was not updated to reflect manual control of the gland seal steam system. No training on how extra RO should assist during event. No multiple operator training.

Experience/Training – Nominal

Event ID (Plant / Date / Report Type)	Event Summary	PSF Description
WGS3 06/24/91 HPS	After RX trip & power cutback, operator stabilized plant and while reducing power, startup feedwater regulating valve failed open and caused increased level in steam generator (SG)2. Operator scrammed RX & initiated MSIV trip to prevent excess cooldown from failed open safety block control valve (SBCV).	Timely response of control room operators due to knowledge and training in procedures and operating principles. Crew had just completed ten days refresher training.
WCS1 09/23/91 AIT	Loss of spent fuel pool level and cooling, loss of gate boot seals. Breaker trip and associated loss of bus pao1.RCS transient induced by loss of 2 of 4 operating reactor coolant pumps (RCP)'s during solid plant operations gave rapid decrease in RCS pressure & RHR heat sink.	Operators' training and familiarity with the plant were assets in coping with the event.

Experience/Training – High

Event ID (Plant / Date / Report Type)	Event Summary	PSF Description
FCS1 07/03/92 HPS	Loss of non-safety-related electrical converter led to a high pressure RX trip followed by a partially failed open safety relief valve. Similar event had occurred here 6 years before.	Plant specific simulator training helped in ability to respond. Trained on LOCA's and loss of inverter scenarios. Also trained on implementing emergency plan. Could be improved to include actions for degradation or failure of computer system.
FCS1 07/03/92 AIT	Loss of load event occurred resulting in RX trip & loss of coolant event. Turbine control valves shut and pressure increased resulting in pressurizer code safety valve and uncontrolled loss of coolant.	Simulator training received was a significant factor in event mitigation. Loss of coolant events included in simulator training. Site specific simulator has provided increased training time & procedure confidence. Emergency planning practiced weekly.

Event ID (Plant / Date / Report Type)	Event Summary	PSF Description
PAV3 02/04/93 HPS	A main feedwater pump high vibration annunciator alarmed while operating at 100% power. Safety injection initiated. RX automatically tripped on low steam generator levels one minute later.	Combined crew experience and training were above the industry norm and contributed to successful performance, however there was no training on conditions of this event. Previous training included command and control. Simulator training was useful.

Procedures – Not Available

Event ID (Plant / Date / Report Type)	Event Summary	PSF Description
CAY1 10/17/92 AIT	Loss of main control room annunciators following power supply loss.	Procedures not available for loss of annunciators. 'Loss of Plant Computer" procedures not used. No list of which alarms were on which power supplies.
MNS3 12/31/90 AIT	Catastrophic failure of two 6-in diameter pipes associated with the plant moisture separator drain system allowed a significant amount of hot condensate system water and steam to be released into the turbine building. Plant process computer lost.	No administrative procedure for evaluating through-wall leaks in the failed system.

Procedures – Available, but poor

Event ID (Plant / Date / Report Type)	Event Summary	PSF Description
NEE3 05/03/97 AIT	Degradation of the high pressure injection system during unit cooldown. Potential damage occurred to 2 of 3 high pressure injection pumps. Letdown storage tank level and related suction head failed to be maintained. Let down storage tank (LDST) erroneously indicated normal level, while actual inventory decreasing.	Shutdown/cooldown procedure didn't guide sensitivity to RCS & systems inventory balancing during cooldown. Procedures provided limited assistance because of non-awareness that letdown storage tank indications were inaccurate. Operations Management Procedure sent mixed messages that perhaps procedures were weak and compliance not required.
IPS3 10/04/90 AIT	Two fuel assemblies were inadvertently lifted out of the core with the reactor upper internals during preparations for defueling. AIT concluded that guide pins were bent during may 1989 refueling.	Procedure for fuel movement deficient. Did not contain detailed information needed on video inspection of assemblies and positioning. Problems with complicated measuring requirements. Format used notes inappropriately; directions in notes & note in wrong place.

Procedures – Nominal

Event ID (Plant / Date / Report Type)	Event Summary	PSF Description
LSC2 08/27/92 AIT	Main turbine trip and subsequent scram due to thrust bearing failure indication numerous equipment problems followed scram.	Good use of procedures assisted in prioritization and addressing individual equipment problems.
PNP1 03/26/93 AIT	Non-safety related 30-inch service water pipe break and subsequent flooding in some plant areas required a rapid reactor shutdown, including a manual scram, and consequent activation of safety equipment. Cause of small leak, enlarged by erosion, unknown.	Good use of procedures assisted in prioritization and combating of individual equipment problems.

Ergonomics/HMI – Missing/Misleading

Event ID (Plant / Date / Report Type)	Event Summary	PSF Description
SGS2 12/13/92 AIT	Loss of control room overhead annunciator system for 1-1/2 hours without knowledge of or response by operating staff.	Operators not aware that computer locked up and annunciators were not working. Failure mode not readily detectable and alternate alert not provided. No human factors review of remote configuration workstation, which lacked human factors features.
PIN2 02/20/92 AIT	Residual heat removal system interruption due to over draining of RX coolant system while attempting to establish stable mid-loop operation conditions, shutting off inservice RHR pump and interrupting heat removal.	Design of the electronic level measurement instruments was incompatible with the nitrogen pressures specified in the draindown procedure. Instruments were essentially unavailable.

Ergonomics/HMI – Poor

Event ID (Plant / Date / Report Type)	Event Summary	PSF Description
FCS1 07/03/92 HPS	Loss of nonsafety-related electrical converter led to a high pressure RX trip followed by a partially failed open safety relief valve. Similar event had occurred here 6 years before.	Arrangement/placement: related displays & controls were located at some distance from each other. Difficulty in obtaining info for failed computer displays. HPSI valve did not have consistent linear controls.
NEE3 03/08/91 LER	Rev 0. While shutdown during refueling, spilled 14,000 g of water from RCS & borated water storage to RX building during valve test. Blank flange installed on wrong suction train. Not on isolation valve tested. Interrupted decay heat removal for 18.5 min.	Incorrect handwritten label in RX building emergency sump identifying wrong low pressure injection suction pipe. No formal labeling.

Ergonomics/HMI – Nominal

Event ID (Plant / Date / Report Type)	Event Summary	PSF Description
PAV3 02/04/93 LER	Rev 0. RX trip due to SG2 water level reaching low RPS trip set point following loss of main feedwater pump A, followed by multiple ESF actuations. Event diagnosed as an uncomplicated RX trip.	No unusual characteristics of the work location (e.g., noise, heat, poor lighting) directly contributed to this event.

Fitness for Duty – Degraded Fitness

Event ID (Plant / Date / Report Type)	Event Summary	PSF Description
HBR2 11/14/93 AIT	Mismatch between actual power and power range nuclear instrumentation during startup, due to fuel assembly error by vendor and operators lack of understanding of core geometry. Power increase caused violation of tech specs, flux tilt & power level anomalies.	Long vendor shifts and personnel illness contributed to breaking or failing to notice damage to a fuel inspection tool, resulting in loose parts in control rod guide tube.

Work Processes – Poor

Event ID (Plant / Date / Report Type)	Event Summary	PSF Description
PAV3 05/04/92 AIT	Loss of non-safety related annunciator and computer alarm systems following a circuit breaker trip alarm verification that created an inadvertent short circuit.	Problems with work order control & personnel safety (electricians failed to use safety equipment, adequate safety precautions not taken). Program barriers not in place for engineering review of modified work orders. Inconsistent with management expectations.
ZIS1 02/21/97 AIT	Following 48 hr LCO and 4 hr TS shutdown statement, Nuclear Station Operator (NSO) initiates improper control rod manipulations during Unit 1 shutdown, inserts rods for 3'43", then rods withdrawn for 1'45" without estimated critical position calculation while RX substantially subcritical. RX tripped for core spray (CS) pump problem prior to criticality. Inadequate reactivity management.	Breakdown in command and control, failure of ops supervision to properly exercise oversight responsibilities for ensuring shift activities conducted in controlled manner. Shutdown (SD) briefing was informal, poorly planned, ineffective. "Event was primarily the result of breakdown in command and control."

Event ID (Plant / Date / Report Type)	Event Summary	PSF Description
WNP2 04/09/95 AIT	Reactor water cleanup valve was operated in violation of procedure cautions and requirements (prohibiting opening of the valve above 125 psig) while attempting to control reactor water level during hot shutdown.	Inadequate communications between control room supervisor (CRS) and shift manager. CRS didn't pay attention to operator concerns, communication was informal and directions were vague. Relief CRO was not informed of valve position. Valve position not recorded in control room log. Inadequate organizational culture. Poor personal work standards were root causes of the event. Management response to prior interpersonal problems of the effected crew was slow.

Work Processes – Nominal

Event ID (Plant / Date / Report Type)	Event Summary	PSF Description
PBS3 01/28/90 HPS	Loss of electro hydraulic control (ECH) and resultant rapid shutdown due to o-ring failure in main turbine control valve.	Competent and constructive communications. Furthered crew ability to function effectively under trying circumstances.
PAV3 05/04/92 AIT	Loss of non-safety related annunciator and computer alarm systems following a circuit breaker trip alarm verification that created an inadvertent short circuit.	Lack of intrusive supervisory involvement in the initiation and performance of routine balance-of-plant electrical work. Successful coordination of short-term corrective actions. Effectively avoided challenges to plant safety systems.

Work Processes – Good

Event ID (Plant / Date / Report Type)	Event Summary	PSF Description
PAV3 02/04/93 HPS	A main feed water pump high vibration annunciator alarmed while operating at 100% power. Safety injection initiated. RX automatically tripped on low steam generator levels one minute later.	Good command & control. Shift supervisor (SS) moved people out of control room, had good overview, and was out of operator’s way, yet readily available to crew. Emergency coordinator duties transferred to available qualified person, enhancing SS oversight ability.

Event ID (Plant / Date / Report Type)	Event Summary	PSF Description
NMP2 03/23/92 AIT	1 of 2 lines supplying off site power to Unit 2 inadvertently tripped, causing loss of control room annunciators. Second trip (power line) led to total loss of offsite power. One of two running emergency diesel generators tripped due to loss of cool water.	SS exhibited good command and control while conducting plant restoration.

Appendix G

The Relative Relationship Among SPAR-H PSFs

Appendix G
The Relative Relationship Among SPAR-H PSFs

Table G-1. The relative relationship among SPAR-H PSFs.

Influence of X upon Y	X1 Available time	X2 Stress/Stressors	X3 Complexity	X4 Experience/Training	X5 Procedures	X6 Ergonomics/HMI	X7 Fitness for Duty	X8 Work Processes
Y1 Available time (ratio of time available to time required)	1.0	Medium to high (stress can increase the time required to process information and perform actions)	Medium to high High complexity can increase the time required)	Medium (greater experience means that less time is required for actions and decisions; shifts the margin in the available time in either direction)	Medium to high (complex or poorly conceived procedures determine how much time one needs to act)	Medium (poor layout can result in increased reaction time, lessening the available time to respond)	Low to medium (illness, high levels of fatigue, or drug abuse may increase time required to decide or act)	Low to moderate (poor shift turn over of information can reduce time available for crew response)
Y2 Stress/Stressors	High (less time may increase stress)	1.0	Medium to high	Medium (more experienced workers may experience less stress)	Low to medium (poor procedure completeness or quality can increase stress)	Low to medium (poor ergonomics can contribute to increased workload and physical and mental stress)	Low (illness can lower the threshold stress effects upon performance)	Low
Y3 Complexity	Medium to high (little time makes the task more complex, simultaneous acts)	High (stress can make the situation appear more complex b/c don't perceive information)	1.0	Medium to high (experience can mitigate the effects of complex decisions through heuristics and actions)	Medium (better procedures reduce complexity)	Medium (poor ergonomics can require more actions per task or that the operator perform more computations and calculations by hand or mentally)	Medium (diminished capacity can result in simple situations experienced as complex or overwhelming, i.e., exceeding channel capacity)	Medium (cumbersome work processes and supervision can increase the complexity associated with maintaining equipment; increasing uncertainty through poor or miscommunication can heighten complexity.)
Y4 Experience/Training	Low	Medium (affects ability to recall information acquired during training)	Low	1.0	Low (procedures can complement the experience level)	Low	Low	Low

Influence of X uponY	X1 Available time	X2 Stress/Stressors	X3 Complexity	X4 Experience/Training	X5 Procedures	X6 Ergonomics/HMI	X7 Fitness for Duty	X8 Work Processes
Y5 Procedures	Low	Low	Medium	Low	1.0	Low (ergonomics for situations can make it difficult to follow procedures)	Low	Medium (particularly important for procedure design review and implementation))
Y6 Ergonomics/HMI	Low	Low	Low to medium	Low (greater experience can mitigate the effects of marginal ergonomics but cannot override)	Low	1.0	Low	Low
Y7 Fitness for duty	Low	Medium to high	Medium (high complexity may induce fatigue or amplify circadian effects)	Low	Low	Low (poor ergonomics such as lifting requirements, can interact with medical conditions or circadian effects)	1.0	Low to medium (there is some evidence that a poor safety culture can result in general lowering of fitness for duty for an entire work group).
Y8 Work Processes	Medium	Medium	Medium (multi-agent complex tasks require greater coordination)	Medium	Medium (procedures can influence the effectiveness or occurrence of work processes)	Low	Low to medium (illness and substance abuse or irregular work cycles can affect crew dynamics and the effectiveness of work processes that are in place)	1.0

* Relative relationship is defined as either low, medium or high.

Appendix H

SPAR-H Development History

Appendix H
SPAR-H Development History

Original Development (1994)

Efforts directed toward development of SPAR-H method focused upon producing a simple, general, and easy-to-apply method, which considers or accounts for actuation, recovery (to the extent that it is present in the PRA model), and dependency through a consistent model of human behavior. A general criticism of HRA methods is the inability to tie these methods back to first principles in human behavior. Generally, methods identify a set of factors believed to be related to performance (e.g., stress and stressors, training, procedure quality), or focus on classes of human error (omission, commission, mistakes, slips), or even general classifications of human behavior (rule, skill, and knowledge), and then manipulate those factors to arrive at a failure rate. The obvious problem with these approaches is completeness. How do we know that the set of identified factors is, in fact, complete? In developing SPAR-H, we began with a model of human behavior and went to operating events and behavioral sciences literature to determine whether the model and its associated elements covered the basics.

To our knowledge, no single HRA method begins with a theory of human behavior, to ensure that all relevant factors are addressed and accounted for, and then works forward to identify demonstrated, underlying mechanisms that are known to influence and be predictive of behavior. To avoid this basic flaw in method development, time was spent in identifying an underlying model of human behavior from which to develop a clearly supportable and complete HRA method for SPAR.

Because there was a need for simplicity and usability, SPAR-H does not consider detail on a finer level than it does. For example, more refined aspects of work process or of information processing and decision making, such as situation awareness and parallel versus serial search strategies, could have been brought into the model, but would have made it difficult to use and interpret. We acknowledged that there was a need for method that was good enough to support the HRA process, which could be improved upon as state of the art in HRA improves.

The existing ASP HRA methodology was developed in 1994 (Blackman and Byers, 1994) and, for clarity and convenience, is hereafter referred to as the 1994 ASP HRA methodology. The enhanced and revised version of the methodology, with minor exception, is the basis for the SPAR-H 2004 revision presented in this report. The 1999 Version is referred to as the simplified plant analysis risk (SPAR) HRA method.

The 1994 ASP HRA methodology was developed to make an order of magnitude improvement in the HRA practice of the accident sequence precursor (ASP) program (the previous method had been limited to four human error probability (HEP) values). The 1994 ASP HRA methodology made use of a two-page worksheet to rate a series of performance shaping factors (PSFs) and dependency factors to arrive at a screening level human error probability (HEP) for a given task.

Noteworthy features of the 1994 methodology were a derivation of PSFs from a psychological model of human behavior, and an explicit dependency model. However, when compared to the open literature and individual plant examination (IPE) HRA data, the dynamic range for HEPs in the 1994 ASP HRA methodology was limited, and the taxonomy for distinguishing the processing (cognition) portion of a task from the response (action) portion of the task proved somewhat difficult for collaborators who were non-human factors and HRA professionals to apply. In addition, a more obvious link to human performance literature and human performance distributions was needed beyond the top-level model. This was addressed in the current version.

1999 Revision

The 1999 revision attempted to enhance the existing accident sequence precursor (ASP) human reliability analysis (HRA) methodology to make it more accessible for the SPAR modeler to apply.

Although it may serve to support other modeling efforts and characterizations of human performance for the risk analyst, the primary function of the revised SPAR-H methodology will still be to support the SPAR models. We believe that the SPAR-H method can serve other functions, such as screening for most HRA applications, and that when placed in appropriate logic modeling structures, SPAR-H can help identify contributions to risk associated with human performance. However, readers are still cautioned that this is a screening analysis tool and not meant to replace complete HRA methods. This being said, analysts must still apply a reasonable standard of investigation and evaluation of scenarios provided by PRA to obtain an accurate analysis.

Simplified Plant Analysis Risk (SPAR) models have been developed by NRC for use in accident sequence precursor analyses for operating plants. These level 1 SPAR models are used to evaluate the estimated conditional core damage probability, given a specific initiating event or the existence of a specific condition at a plant. These models were developed initially as simplified models, i.e., restricted number of initiating events (only those that were considered most common [transients and loss of offsite power] or bounding for safety-related systems not challenged by the common events); support systems when not modeled explicitly (only impact on frontline systems modeled); and basic events rolled-up into super components, resulting in smaller fault trees.

Subsequent to the development of the first version of 75 plant-specific SPAR models, changes and additions to the models were identified and implemented in Revision 2. Revision 2 models consist of the following: treatment of emergency ac power was expanded; plant-specific features impacting station blackout were added, in addition to certain plant features identified in the licensee's IPE submittals; and the BWR models were modified to include interdependencies among the power conversion and the condensate and feed water systems. The models were revised to accommodate the comments generated from a quality assurance review and are now designated as the "Revision 2QA" SPAR models. Since some plants have been shut down while model development was underway, there were 72 Revision 2QA models, which were made available for use by mid-1998 (Holahan et al. 1998).

Scope. The work to revise the ASP HRA method was cast as four subtasks:

1. Review other current and emerging HRA methods for similarities and differences
2. Adjust PSFs and/or influence weights based on the review results and user comments
3. Review and adjust dependency calculations based on the review results and user comments
4. Adjust base HEPs based on the review results.

The revision of the 1994 ASP HRA Methodology was completed in 1999 by the INL and remained in draft form. It was field-tested by NRC inspectors, SPAR model developers, and HRA analysts. Comments and experiences with the method were collected, and the method was addressed again in 2003 with expansion of the screening method to LP/SD scenarios. This report documents the latest version (2004 revision) of the SPAR-H method.

2004 Revision

Uncertainty. The SPAR-H method as revised in 1999 only determined point estimates for HEPs. It was desirable, for purposes of PRA, to develop a method whereby uncertainties in the HEP estimates could be propagated in the PRA. Therefore, we set out to determine the uncertainty distributions for SPAR HEPs.

Distribution of HEPs. Previous approaches to HRA uncertainty. Since publication of THERP, the lognormal distribution has become an accepted distribution for skilled performance. Sträter (2000) has added further weight to the argument for using a lognormal distribution as set forth in THERP for HEPs.

THERP postulates a lognormal probability density function (PDF) with a standard deviation of 0.42. A SD of 0.42 was obtained by assuming a 4:1 range ratio between the 95th and 5th percentiles for tasks performed under routine conditions.

However, it then goes on to say that the range ratios used in reliability analyses of NPP tasks are considerably wider than the nominal 4:1 ratio; thus, calling into question that approach.

Our review of the human performance literature suggests that human performance may often follow either a normal log distribution, but that it also may follow a quadratic, or cubic distribution. Also, the transformation from success space to failure probability is not so straightforward. We believe that the mean value should be preserved. Also, we advocate the use of a beta distribution to model HGPs. Specifically, we use the constrained noninformative distribution, which maximizes uncertainty about the mean HEP valve. This distribution provides an adequate representation of the upper bound and truncated at a value of one.

Analysts are therefore encouraged to use the CNI approach to uncertainty calculation discussed in Section 2.6 of this report.

Sources of Uncertainty

Unsurprisingly, the estimation of HEPs has uncertainty associated with it. It is obvious that our industry has done a much better job in collecting, collating, and analyzing equipment failure data than human errors. As Swain and Guttmann (NUREG/CR-1278 1983) point out, uncertainty in HRA comes from such sources as:

- Dearth of the type of human performance data useful to PRA/HRA
- Inexactness of models of human performance
- Inadequate identification of PSFs and their interactions and effects
- Analyst skill and knowledge limitations
- Variability in performance (both within the individual and between individuals).

All of the above, except the last, fall mainly into the category of epistemic uncertainty. On the other hand, the innate variability in performance, particularly within individuals, appears to be so intractable that it may as well be regarded as random.

Comparison of LP/SD and at-power conditions. As a result of a qualitative comparison of LP/SD and at-power conditions that was performed, it was determined that a separate worksheet for LP/SD should be developed. This worksheet is presented in Appendix B. Findings from field test results of the SPAR-H method led to improvements in the LP/SD and at-power worksheets. The following enhancements to earlier versions of the worksheet were implemented:

1. LP/SD Worksheet Enhancements

   PSF time available for actions. The dynamic range of influence for expansive time available (50x nominal) was changed. The range of effect for expansive time now uses a multiplier of 0.01. When time available is determined to be 5x nominal, then a multiplier of 0.1 is used.

   PSF Procedures. An additional level of influence was incorporated for LP/SD. Incomplete or partial procedures influence the base HEP by a factor of 20. This influence is present for action and diagnosis tasks. Analysts commented that this assignment would be potentially valuable for at-power conditions as well and this level has also been applied to the at-power worksheets.

   PSF time available for diagnosis. Time available multipliers were developed. Diagnoses with extra available time available ranging from less than or equal to 2x nominal are assigned a multiplier of 0.1; expansive time (defined as >2x nominal) is assigned a range of effect from 0.1 to 0.01 that may be assigned by the analyst. This better reflects the increased uncertainty and longer time horizons associated with a number of LP/SD tasks.

   PSF Complexity. An additional level of influence for favorable complexity (i.e., obvious diagnosis) was developed. The multiplier associated for this category is 0.1.

2. At-power Worksheet Enhancements

   PSF time available for actions. The dynamic range of influence for expansive time available was changed. The range of effect for expansive time now uses a multiplier of 0.01 and in addition to the use of absolute minutes in earlier versions of SPAR-H, the relative time available in conjunction with the time required for task performance has been taken into account.

PSF Procedures. An additional level of influence was incorporated. Incomplete or partial procedures influence the base HEP by a factor of 20. This influence is present for action and diagnosis tasks.

PSF time *available for diagnosis*. The influence of expansive time (≥24 hours for diagnosis for at-power conditions) was changed from a multiplier of 0.001 to 0.01.

APPENDIX I

SPAR-H Review Comments

APPENDIX I
SPAR-H Review Comments

Table I-1 on the following pages presents response to comments received during the peer review of the revised SPAR-H method. The peer review followed an iterative format, in which comments were solicited and received throughout the development of the document. After completion of the draft NUREG report, a formal review period followed during May – October, 2003. The following individuals participated as peer reviewers.

NRC
Suzanne C. Black
James Bongarra
Mike Cheok
Susan Cooper
Dave DeSaulniers
Mike Franovich
Claire Goodman
Hossein Hamzehee
Chris Hunter
Paul Lewis
Erasmia Lois
Gareth Parry
J. J. Persensky
Marie Pohida
Nathan Siu
Dave Trimble
Peter Wilson

ERIN
Steven Mays

ACRS PRA Subcommittee
George Apostolakis
Dana Powers
Steve Rosen
J. Sieber

Sandia National Laboratory
John Forrester
Hugh Whitehurst

EPRI
John Gaertner
Nick Grantom
J. Grobbelaar
Frank Rahn
Gary Vine

SAIC
Alan Kolaczkowski

Buttonwood Consulting
Dennis Bley

Scientech
Jeff Julius

Brookhaven National Laboratory
John O'Hara
John Lehner

INL
Ron Boring
Bruce Hallbert
Pat McCabe
Jennifer Nadeau
Dave Pack
Marty Sattison
April Whaley

A high-level summary of major changes made in response to the formal peer review comments follows:

- The scale the time available PSF was modified from absolute time intervals in minutes to time intervals relative to the time necessary to complete a diagnosis or action.
- The definition of the stress PSF was broadened to include stressors, encompassing both psychological and physiological components of stress that influence behavior.
- The definitions for diagnosis and action, as well as joint diagnosis and action tasks, were clarified in order to make the SPAR-H worksheet usage more intuitive for analysts.
- Comparisons between SPAR-H and other HRA methods such as THERP, SHARP, and the ASME standard were clarified.
- The SPAR-H worksheets now include an adjustment factor to ensure that the HEP cannot exceed 1.0.
- An additional PSF level for "insufficient information" was added to all SPAR-H worksheets. This PSF level is weighted identically to the nominal PSF level, but it acknowledges circumstances when information about PSF level assignment is unavailable.
- Where appropriate, levels were added to the PSF tables to account for the positive influence of certain PSFs. It is assumed that in regulatory space, most PSF assignments will center around the negative influence of PSFs.
- Throughout the report, numerous clerical errors and inconsistencies were corrected.

Table I-1. Formal peer review comments and responses.

Comment	Source	Response	Scoping
1. The SPAR-H Method does not consider any credit for the opportunity to recover from an operator's error that would be provided by additional crew.	NRC	Crediting recovery or failure to act is handled indirectly in the model. It is available in one of two ways: first, through explicit modeling on the part of the analyst and, second, by manipulation of PSFs.	See Section 2.8.
2. The Time Available Nominal shaping factor criterion for power operation appears to use 20 minutes as a lower bound. (Also see Comments 8, 14, 30, and 78)	NRC	A relative time scale with some time limitations is being adopted in response to similar questions. A minimum time is also presented because there is little evidence that situations whose time is too compressed allow for recovery even if the action or decision does not take long.	See Section 2.4.4.1.
3. In the SPAR-H Method, no consideration is taken of the strength or quality of the information or cues available to the operator regarding the necessary actions that must be taken to mitigate an accident initiator.	NRC	In a number of situations it is highly likely that cue strength is important. In SPAR-H, cue strength is evaluated in the assignment of the Ergonomics/HMI PSF.	See Section 2.4.4.6.
4. When one uses the SPAR-H Method worksheet, it appears that there are more ways for the baseline probability for a Diagnosis task or an Action task to be increased than there are for this probability to be reduced.	NRC	Yes, the PSF levels are negatively skewed. It is expected that the analyst working in regulatory space will be reviewing events where the concern will be that more influences are expected to be negative rather than positive.	See Sections 2.4.3 and 2.5.1.2.
5. The differences between the SPAR-H Method and other acceptable HRA approaches such as EPRI or THERP are not clear.	NRC	SPAR-H is a simple worksheet driven HRA approach that is a composite method spanning several others. It was developed to support ASP models and has grown to include support of the significance determination process (SDP), and to aid in other uncomplicated HRA efforts. At the time the method was developed details concerning the range of influence for PSFs and a detailed listing of PSFs were not available. Hence, the SPAR-H tables do not make direct comparison with the EPRI CBDT approach. While going to press, more information on the EPRI method was available and information regarding that method has been incorporated in the latest revision. References to THERP and the comparisons with THERP are contained in various sections within the body of the document. In general, SPAR-H offers the advantages of unifying disparate approaches to HRA modeling while requiring the analyst to consider a consistent, full range of PSFs and expands the diagnostic approach found in THERP to include other considerations such as dependency on subsequent events and PSFs.	As resources permit, detailed comparison between SPAR-H and EPRI methods could be conducted.
6. The SPAR-H Method acknowledges the issue of interactions among the PSFs but offers no explicit way of handling the interactions and assumes the PSFs can be multiplied as independent influences. Perhaps simplified guidance and a worksheet could be derived that would allow the user to define strong relationships among the PSFs.	Sandia, SAIC	Beyond determining an adjustment factor to assist in instances where double counting among highly related factors is moderately possible, no utilization of a matrix or other process is currently intended. General guidance is that analysts be sensitive to the possibility of double counting and make their PSF assignments accordingly. The suggested adjustment factor is located in a calculation space provided in the SPAR-H worksheets.	As resources permit, could be performed at a later date.
7. Several issues regarding the appropriate assignment of the nominal rate should be addressed: (a) Guidance as to how to define extreme failure or high reliability situations may be appropriate. (b) There should be a system that ensures consistent linking of learned factors to the assigned PSFs.	Sandia, SAIC	Guidance on finding extremely high or low reliability situations is related to declaration of context. In SPAR-H, this is done bottom-up through the assignment of the PSF values. There are no current plans to develop additional PSFs or to develop linking of learned factors acquired through event analysis to the assigned PSFs. This could be achieved through establishing a SPAR-H user group or by expanding the scope of the current SPAR user group.	Out of scope.

Comment	Source	Response	Scoping
8. The definitions of the various PSFs do not seem appropriate in all cases. For example, assigning "barely adequate" as less than 20 minutes fails to recognize that for some actions, 1 or 2 minutes may be "lots of time," and for another action, even one hour may be barely adequate. We recommend re-examining the eight PSFs to ensure that they reflect the dimension appropriately. As part of this, consider "relative" definitions. Also, consider tradeoffs such as whether recent, situation specific simulator training can be more important than whether an operator has less or more than six months of experience. (Also see Comments 2, 14, 30, and 78)	Sandia, SAIC	The PSFs are anticipated to be applicable to the majority of events and situations to be evaluated but probably not to all. If the time available is less than 30 minutes and not thought to influence performance beyond the normally expected range or if the analyst determines that there is an insufficient amount of information to make an appropriate assignment, he or she does not have to assign a negative value to time available. For actions, the time PSF has been modified to relative time multiples, which is the ratio of time available to the time required.	See Section 2.4.4.1.
9. Some PSFs, e.g., fitness for duty and ergonomics/HMI, should be examined only under special scenarios. Additional discussion as to when to address such factors would be useful.	Sandia, SAIC	Fitness for duty and ergonomics/HMI are more likely to be used in performing retrospective analysis where such information may be available from comments determined from the AIT report. Review of behavioral sciences literature and events determined in NUREG/CR-5763 support the use of these factors. Prospectively, the analyst would need access to drawings, have performed walkdowns, reviewed near-miss databases, etc. before assuming ergonomics to contribute beyond the nominal case. Instructions currently acknowledge that for model development the generic nominal value can be used and that the PSF assignment be re-evaluated when applied to a plant specific case.	See Sections 2.4.4.6 and 2.4.4.7.
10. It is recommended that the dimensions related to dependency be re-evaluated to be sure that they are the best choices (given the expected applications of SPAR-H) for post-initiator actions.	Sandia, SAIC	The dimensions in the dependency model could be re-evaluated at a later time. Currently, these are offered as a refinement to some basic work by Swain et al. (NUREG/CR-1278, -4772) and have been applied in the SPAR-H process since 1999.	Out of scope.
11. Check for consistency and cross-referencing of section numbering.	Sandia, SAIC, EPRI	This suggestion has been implemented.	Throughout report.
12. Consider deleting Section 2.7.2. The data from the studies cited seem very far removed from the PSFs in the SPAR-H method and their multipliers.	Sandia, SAIC	The material from this section is included because there has been no externally distributed version of SPAR-H prior to this report and we think that some background in these studies should be provided.	See Section 2.7.2.
13. Looking at the Shutdown SPAR LP&SD event trees, based on the SPAR-H definition of diagnosis, the top event ("Operator diagnoses the event") should be removed from all the PWR Loss of Inventory Trees, the Loss of Offsite Power trees, and the Loss of RHR trees.	NRC	The decision whether to remove operator diagnosis from all LP/SD trees for PWR loss of inventory, loss of offsite power trees, and loss of RHR trees is beyond the scope of the present report and is worthy of review by the SPAR User Group and PRA analysts. The necessity of the diagnosis basic event may prove to be a function of the context of the scenario including existing plant complexity factors, availability of indication, and the specific plant involved.	See Sections 3.2 and 3.3.
14. Using multiples of nominal time to define available time categories seems preferable to using actual time intervals. (Also see Comments 2, 8, 30, and 78)	Sandia	This approach is implemented with minor modification. Also the analyst has the opportunity to address the potential for overly conservative assignment by use of the "Obvious diagnosis" category available with Procedures.	See Section 2.4.4.1.

Comment	Source	Response	Scoping
15. The definition of stress used is extremely broad, covering both psychological and physiological stress. The stress that is likely to degrade performance, especially during an emergency, is acute psychological stress, but individual differences, especially experience, affect the degree of performance degradation. One approach is to change the name of the PSF from "Stress" to "Stressors." We then acknowledge not knowing if particular individuals experience psychological stress.	Sandia	We have broadened the definition of stress to include "stressors." The analyst may select an appropriate level of experience if he or she, upon review, believes that individual differences in stress are likely to appear as a function of experience and that he or she has enough data to determine the level of experience for rotating crews.	See Section 2.4.4.2.
16. Regarding experience and training, the high multiplier of "3" might be correct under normal conditions. However, under emergency conditions, especially conditions that are life threatening, it seems that a higher multiplier is needed.	Sandia	The argument is intuitively appealing. However, the range of influence for training and experience in SPAR-H mirrors that used in other first generation methods. The application of SPAR-H for use in risk/vulnerability studies where such factors as heat, fire, explosion, debris, loss of communications, and inadequacy of existing procedures may figure into personnel response and plant risk was not part of the current project scope.	Out of scope.
17. An operator who is fit for duty under normal conditions might not be fit for duty in life-threatening emergencies. Under such circumstances, good fitness means that uncommon physical exertion will not degrade performance.	Sandia	Agreed. Again this application extends the boundaries of the method. We would suggest using the appropriate level of fitness for duty for this context and explaining the basis of the assignment in the mandatory comments section of the worksheet. This is an area for potential further development. (Also see Comment 16.)	Out of scope.
18. A number of corrections are necessary. (a) A correct reference to IEEE Standard 1082 should not include a "P" designation. (b) The introductory References section is missing the 1999 Apostolakis citation. (c) IEEE Standard 1574 should be cited as "P 1574" as it is a draft document under development. (d) In Appendix C, page C-10, the dependency condition table indicates that the dependency for the task failure is "low." However, in the calculation of task failure probability with formal dependence at the bottom of the page, the value for "moderate dependence" is used. (e) In Appendix C, page C-10 (and elsewhere), the nomenclature for Probability without Formal Dependence (Pw/od) and that for Probability with Formal Dependence (Pw/od) appear to be incorrect. The same nomenclature is used to describe two difference dependencies. (f) In Appendix G, Table G-1, the relationship as depicted in the influence diagram between "stress" and "fitness for duty" does not appear to be in agreement with the explanation/ relationship level provided in Table G-1.	NRC, EPRI	(a) Corrected (b) Corrected (c) Corrected (d) Corrected (e) The inconsistency has been corrected (f) The Table has been modified to be consistent with Appendix G. The diagram is consistent with a path diagram where bi-directionality of effects is modeled, rather than an influence diagram where the directionality is typically one way.	Throughout report.

Comment	Source	Response	Scoping
19. The report would benefit from being reorganized; the current version is confusing in that the theoretical basis and the comparisons with other methods are intermingled with the description of the method. It would be more usable if the report were rewritten with the main body providing a description of the method, and the detailed discussion of the human behavior model, the comparison between the models, and other historical material moved to Appendices.	NRC	Different organizational schemes for the document have been under discussion. However, it was determined that it would be better to have users understand the technical basis of the method by forcing them to review the history and issues associated with the method prior to learning the mechanics of the method. It is believed that this will help ensure more consistent application by users.	Out of scope.
20. In the Executive Summary, the first sentence in the second paragraph is misleading. The SPAR-H Method is not "a method for predicting human error," but a method for estimation of the probabilities (HEPs) of the human failure events included in the SPAR PRA models.	NRC	Corrected.	See Executive Summary.
21. It is stated that the SPAR-H Method can be applied at the task or sub-task level. The definitions of task and subtask suggest that a task is modeled at the level of a basic event of the SPAR Model, which may include many sub-tasks. Since the method is based on adjusting the base case HEP, it is difficult to see how this can be performed in a consistent manner if the analyst can choose to use the SPAR-H method for tasks or subtasks within the same PRA. Different analysts may use different although internally self-consistent approaches; inconsistencies will emerge when comparing HRAs.	NRC	Decomposition is dictated by the approach of the HRA analyst to the PRA and by the circumstances surrounding what is being modeled. We do not, a priori, suggest which level of decomposition is most appropriate for all or even specific situations. This is a challenge for HRA in general. When inter-analyst comparisons are made, even second-generation HRAs may present different values and inconsistencies in what is considered, including the level of decomposition. Finally, it is thought by the authors that the degree of difference among analysts will be constrained by the use of the worksheets, which forces consistent consideration of the same PSFs, dependency, and approach to uncertainty. A benchmarking exercise would benefit the field.	Answered but benchmarking against other HRA methods or among analysts is desirable but out of scope.
22. It would be better to refer to SHARP1 rather than the original SHARP as a framework for performing HRA. The revised SHARP1 method discusses the identification and definition of the human failure events in a more systematic and complete way than did SHARP.	NRC	We are in the process of obtaining access through the NRC PM to SHARP1 (EPRI 1999) from the EPRI website. At the time that this report went to press, SHARP1 was not yet available for review. We therefore acknowledge the importance of the reference but show only limited discussion of particular aspects of SHARP1 within the body of this report.	Out of scope.
23. In the Executive Summary, the discussion in the first paragraph of the section entitled "Overview" is confusing, particularly in differentiating between diagnosis and action.	NRC	Additional guidance differentiating diagnosis from action has been added to the definitions portion of the report, and this information will be brought forward to the executive summary.	See Executive Summary.
24. The characterization of the SPAR-H method in Section 1.1 is overstated. SPAR-H is a quantification tool. It is not structured to help identify the human failure events that should be included in the PRA model; this is a function performed when developing the accident sequence models.	NRC	Yes, SPAR-H is a quantification tool. Accident sequence model development does help identify HRA events or sub events. In prospective analysis, the HRA approach can help to identify errors of commission that are then fed back into the PRA process. In retrospective analysis, the same is true; HRA sub events not identified in the plant PRA but which had an impact upon risk can be identified, modeled, and quantified and the PRA model updated accordingly.	See Section 1.1.
25. Since SPAR-H is primarily a quantification tool, it is not necessary for this document to discuss different HRA approaches for identifying the human failure events (HFEs) for which the tool is intended to provide probabilities (HEPs). So, for example, the part of Section 4.2 that discusses the ATHEANA approach to HRA is superfluous.	NRC	The user audience is anticipated as being diverse. Any HRA including SPAR-H should not be performed in a vacuum. Although not a part of SPAR, per se, presenting recognized search strategies does not, in our opinion, take away from the document. It is hoped that readers will access these reference materials in greater detail. We did not develop our own strategy because there are several good ones out there including ATHEANA and EPRI approaches.	See Section 4.2.

Comment	Source	Response	Scoping
26. What is meant by diagnosis is not altogether clear. With the preponderance of symptom based procedures, there are very few real diagnosis events. Rather, the concern is more whether the symptoms have been observed and interpreted correctly to transition to the appropriate set of instructions.	NRC	The definition for diagnosis has been clarified. Most of the plant models have diagnosis events for which HEPs are required, and it would be imprudent not to do so. Also a number of actions observed during operating events have indicated errors in planning and other cognitively demanding tasks, still others involved improper prioritization of activities within the corrective action backlog, or improper resource allocation. The analyst can model entry into the correct procedures and would probably make use of the ergonomics (i.e., cue strength, systems feedback, simultaneity of faults), training and experience, procedures, and work processes in determining the appropriate HEP.	See Section 2.2.1.
27. In the case of continuous action pages, the operator may be required to monitor several indications while taking actions. This is a significant degree of cognitive activity. Would this be modeled as diagnosis rather than action? What is the guidance?	NRC	This situation appears to involve a combined or joint diagnosis and action HEP, instructions for which are present on the worksheet. Analysts would look closely at time available, complexity, training, and stress for these activities.	See Section 2.2.3.
28. Mistakes can have a significant common cause failure potential. When considering dependency in Section 2.3, SPAR-H provides no guidance on how to determine whether an error is a slip, lapse, or a mistake. Therefore, this discussion is superfluous, or needs to be expanded upon.	NRC	Intuitively we believe that mistakes can have a significant common cause effect. We are less certain regarding the extent to which other failure types can contribute to common cause. The determination of the potential error type by the analyst is part of the HRA search process and PRA scenario development and not part of quantification per se. That is why we mention its importance. The details of how to discover and model these various error types are to be found in other references. The point to be made is that SPAR-H can be applied to any or all of these potential error types.	See Section 2.3.
29. Currently, there are two base case HEPs, one for diagnosis and the other for action. Does it make sense to consider two different cases for diagnosis, one for the case where the crew is in a knowledge-based mode and another for the procedure following model? An alternative would be to handle such differences through one of the PSFs, e.g., complexity. If this is the case, it should be clearly discussed in Section 2.4.5.	NRC	Our approach at this point in time has been to address the different diagnosis states by PSF assignment using procedures and complexity and not to distinguish between diagnosis differences for knowledge-based versus rule-based, i.e., procedures, domains. Some PSF levels such as "obvious diagnosis" could, conceivably, apply to either situation. We would expect more diagnoses in LP/SD to be in the knowledge realm and some subset of those diagnoses to be associated with different degrees of complexity. Research could help to determine the extent to which given the same scenario, some crews could be operating in a mode (i.e., skill, knowledge, rule) different than would be other crews.	See Sections 2.2 and 2.3.
30. It's not clear that a nominal time can be defined in terms of a specified number of minutes. The nominal time should be related to the strength of the signature of the event, and the degree to which the operator is trained to recognize it. (Also see Comments 2, 8, 14, and 78)	NRC	A modification to levels of time available has been determined and is contained in the worksheets and in the definitions portion of this report. The present approach assumes that the role of training and strength of the signature of the event (i.e., cue strength or systems feedback) can be represented as a PSF influence.	See Section 2.4.4.1.
31. It is likely that PRA analysts will choose a level of stress based on some other PSF, such as the time available. Since this is already accounted for, it would mean double counting. The levels of stress need to be established taking into account the information on the context that can be gleaned from the SPAR PRA models.	NRC	We have broadened the definition of stress to include stressors, which may make it easier for analysts to make stress level assignments. We agree and have assumed that analysts would help to determine the level of stress based on their understanding of the context of the situation as opposed to one or two other PSFs. When situations are highly negative, we would expect a number of PSFs to be negative as well. Double counting is a concern, and we attempt to address the PSF inter-relationship issue elsewhere in this report but believe more research is needed. Finally, we have included an adjustment factor to the worksheet to reduce the potential effects of double counting on HEP estimates.	Out of scope.

Comment	Source	Response	Scoping
32. In Section 2.4.4.3 about the Complexity PSF, should there be separate discussions of the diagnosis and action? Some actions, e.g., pump recirculation, are relatively easy to diagnose but require a very focused activity.	NRC	On a plant specific basis, we would expect the analyst to make use of the "obvious diagnosis" category in order to reduce conservatisms used in employing the nominal rate. We agree with the reviewer, that it is possible to have a joint HEP where the task is complex but the diagnosis portion of the HEP is less complex. Hence the reason for separate worksheets when constituting the joint HEP.	See Section 2.4.4.3.
33. The section on Experience and Training seems to suggest that it is the crew experience and level of training that is most important. However, the level, frequency, and type of training may vary from scenario to scenario, and this might be a more important factor when assessing the relative HEPs for the different HFEs.	NRC	Frequency of training is now factored into the definition of levels of experience and training PSFs. To the extent that the HRA analyst has knowledge of the crews' scenario-specific training this information should be factored in the training and experience .PSF level rating.	See Section 2.4.4.4.
34. Examples for the definition for Nominal Ergonomics for shutdown in Section 2.4.4.6 should include the availability of RCS level instrumentation and RHR system instrumentation for BWRs. For PWRs, the PSF definition of Nominal Ergonomics should include the availability of RHR system instrumentation, the availability of RCS temperature instrumentation, and the availability of RCS level instrumentation.	NRC	This addition has been implemented and can now be found in Section 2.4.4.6. Note: In general, we are concerned about placing too much information in the general instructions because the scope can easily become too large and exceptions to the examples can routinely be found. It is safest for the SPAR-H analyst to list the available instrumentation when s/he indicates a nominal rating on the worksheet. We have implemented documentation for nominal assignments as a requirement.	See Section 2.4.4.6.
35. In Section 2.4.4.8, the issues related to Work Processes in the control room, e.g., inter-crew communications could be different than those relevant to in-maintenance activities. Expanding the examples in this section, where possible, is essential.	NRC	In documenting the method, attention to detailed analysis regarding work processes associated with maintenance activities has not received great emphasis. We agree that development of additional work process examples relative to work processes would be beneficial. This could include informing the control regarding status of planned or current in the field activities as well as lock out tag out status of equipment. See 34 above.	Out of scope.
36. The dependency between HFEs is driven by the context of the accident sequence. While it is not necessary to take account of the positive dependency effect on the probability, two failures separated by a success may strengthen the case for independence between these HFEs.	NRC	Yes, dependency between human failure subevents can be driven by the accident sequence. It could also be driven by continued use of a flawed procedure and other considerations. We agree. In general, separation of the two failures by a success would strengthen the argument for independence. There may, however, be instances where this is not the case.	See Section 2.6.
37. Should diagnosis and action failures be modeled separately? This is largely a question for the system analyst. If the impact of both failures is the same, there is no need to represent them separately. When, however, there is a potential dependency between the diagnosis of two serial events, then it may make sense to separate the terms.	NRC	This gets to the question of whether or not to use a combined diagnosis/action HEP that is allowed on the worksheet and is a situation specific decision. When there is serial diagnosis, we agree with the reviewer. Separate the terms, and evaluate the second diagnosis for dependency influence.	See Sections 2.2 and 2.6.
38. When calculating the HEP, should the success in diagnosis be accounted for when adding in the probability of failure to perform the action?	NRC	Currently, we are somewhat conservative in estimating the HEP. We do not add in the success.	See Sections 2.4.3.
39. The last paragraph of Section 2.7.1 is incomprehensible without having a copy of THERP open to the right page. More background information is necessary.	NRC	The section has been clarified.	See Section 2.7.1.
40. The purpose of Section 2.7 is not clear. In some sections, the focus seems to be on the representation of uncertainty; in others, it is more related to the shift in the mean as a result of the strength of a PSF.	NRC	The purpose of 2.7 is to describe how SPAR-H fits into a PRA using Bayesian methods. Part of this discussion must, therefore, center on the how and why a certainty uncertainty approach is used in lieu of others. Also, since SPAR-H uses PSFs as thresholds to justify movement of an expected value, this discussion is also applicable to this section.	See Sections 2.7.1 and 2.7.6.

Comment	Source	Response	Scoping
41. Sections 2.7.1, 2.7.6, and 2.7.7 seem to fit more naturally in Section 2.6, since they are strongly related to the discussion of the uncertainty distribution.	NRC	We have opted to break out dependency and uncertainty discussions separately because we believe them to be worthy of equal consideration.	See Section 2.7.
42. The focus in Sections 2.7.2 – 2.7.4 seems to be on demonstrating that the impact of certain PSFs on human performance can be represented by specific distributions. This suggests that they are related to the strength of the PSF, which is not uncertainty as used in this report, but it represents a variability in human performance as a direct result of a PSF.	NRC	The reviewer is correct; the section does present the range of influence of PSFs on human performance. PSFs need to be represented in the method, and there is a quantitative relationship among PSFs and performance. The issue of the uncertainty regarding a PSF or combinations of PSFs is not addressed separately from the uncertainty surrounding the mean HEP. PSF uncertainty is not well researched in HRA but is a reasonable future topic.	Out of scope.
43. Section 2.7.5 seems to undermine the model of independent PSFs. Figure 2-4 may be an honest assessment of the complexity of the problem, but it just reinforces this message.	NRC	This argument has been made by different reviewers. We agree that it is by convention that we in the HRA community (as evidenced by a number of methods, SPAR-H included) view PSFs as independent when performing calculations. Currently, the burden is on the analyst to be vigilant in preventing double counting. Research in this area is highly desirable. Appendix G lists some of our ideas regarding potential relationships that need to be determined by review of operating events data. Finally, we provide an adjustment factor on the worksheets to help reduce the influence or potential for double counting.	Out of scope.
44. Section 2.8 reads as if the authors are suggesting that all recovery actions, even those resulting from a second person checking in preinitiating events, should be modeled explicitly. This would unnecessarily complicate the model for HFEs that are typically not significant contributors.	NRC	Not all recovery actions must be explicitly modeled. The analyst can also use work practices for a second checker, if the facility routinely uses second checkers to good advantage. Decomposition and representation will be a function of the scenario and the way in which the analyst has accounted for human performance in the rest of the HRA.	See Section 2.8.
45. In Section 3.1, there is a subsection called "validation of PSFs against operating events." What does this mean? It is clearly not a calibration of the factors in any numerical sense.	NRC	We agree that validation implies actions other than those carried out by the authors. The sentence in question has been reworded as "reviewed against operating events." In NUREG/CR-5763, human performance influences in high profile events subject to ASP analysis were identified. These influences can be mapped to the PSFs present in SPAR-H.	See Section 3.1.

Comment	Source	Response	Scoping
46. The comparison of SPAR-H with the ASME Standard should be focused on Tables 4.5.5-2(d) and 4.5.5-2(g), since these are the tables that address the quantification method.	NRC	Table 4.5.5-2(d) of the ASME Standard refers to the assessment of the probabilities of the preinitiator human failure events and calls that they be addressed via a systematic process. It notes that THERP and ASEP are acceptable methods. SPAR nominal rates, PSFs, and range of effects have been calibrated against THERP and ASEP and should meet the criteria. The approach does call out differences among screening and detailed assessments. SPAR-H is a simple HRA method and does not differentiate between screening and detailed analysis; all actions or diagnoses are subject to the same procedure. We have no equivalent to ASME category I. We call for the analyst to note the quality of written procedures or administrative controls, and the quality of HMI, which are category II and III items for ASME. We are less detailed on establishing the maximum credit that can be given for multiple recovery opportunities. SPAR-H assesses the potential for recovery of preinitiator or post maintenance or post calibration tests through the use of PSFs such as the work process PSF. Independent verification using written check-off lists, work shift or daily checks, and other factors should be noted in the comments field of the work sheets. Otherwise the nominal HEP is thought to encompass recovery as a function of self check or check by others. If there is reason, then the analyst may explicitly model and quantify the recovery using logic structures and SPAR-H values. SPAR does allow for dependency and providing point estimates as called forth in this table. Finally, the analyst is required to check the reasonableness of HEPs in light of the plant's history procedures, operational practices, and experience. SPAR-H suggests that analysts always refer to operational history to help inform and check HEPs. This is consistent with guidance suggested by ASME.	See Section 5.2.
47. In the example in Appendix C, it would be helpful if the information required for the analysis were to be summarized as an example of the sort of documentation needed to apply the method. What is given is essentially a summary of the event tree structure. Some important information that is missing includes: (i) an estimate of the time window for making the diagnosis, (ii) the information required to recognize an SGTR, and (iii) the procedural guidance that helps to lead to the diagnosis.	NRC	This information was excerpted from another report. We agree that at least a listing of the type of information necessary to support the analysis should be included. Recent events preclude a detailed listing of this information, but the point is well taken. Although we are constrained by the need not to release sensitive information, we have added a generic event tree to further clarify the existing example.	See Appendix C.
48. The examples of PSF characterization in Appendix G are for events. An equivalent for HFEs in a base case model might be helpful.	NRC	The PSFs are mapped to operating events as opposed to the actual base models. There is some mapping of PSFs to base case models in NUREG/CR-6753, Appendix C.	See Appendix G.
49. An issue that seems to be overlooked is a qualitative screening process to identify which PSFs might be important for a particular human error evaluation, and if any PSFs that are not defined will dominate. It appears that the SPAR-H method assumes that the fixed list of eight PSFs is sufficient. Ideally, a way of estimating the impact of non-modeled PSFs should be addressed.	EPRI	SPAR-H purposefully, with the intent of forcing consistency, requires that the same set of PSFs always be applied (evaluated) for every HEP under consideration. PSFs that the analyst feels might dominate will have to be mapped to existing PSF structure and basis for this explained in the comments column. We do believe the list of eight is sufficient for a simplified HRA approach.	See Section 2.4.4.

Comment	Source	Response	Scoping
50. The authors should fully address the relationship between the input factors and the conversion to probabilities within this document, rather than relying on the internal processing of SAPHIRE to carry out this step. SAPHIRE automatically converts the raw inputs into the mean value of a constrained non-informative (CNI) distribution, which keeps all values between 0 and 1.0. The basis for selection of the CNI distribution versus alternate methods (e.g., log logistic) should be further explored since it is not provided in the text.	EPRI, NRC	SPAR-H, when used in a PRA model, utilizes a "Bayesian" setting to represent uncertainty. When this approach is applied, the application should be able to defend any modeling assumptions used during the analysis. Ad hoc methods such as classical statistics via regression analysis or arbitrarily selecting distributions such as log logistic are not defensible in the context of SPAR-H. Consequently, the INL, in defining the uncertainty, focused solely on the facts that (a) the HEP is bounded between 0 and 1, (b) we believe that the result from the SPAR-H worksheet represents an expected value, and (c) we really do not know how diffuse the HEP distribution is for specific events. Using these three assumptions leads one to some type of maximum entropy distribution for the uncertainty. Coupling this general distribution type with the fact we believed we know the posterior expected value then directly implies use of the constrained noninformative (CNI) distribution as discussed in the text. Of course if evidence specific to certain human events provide information related to the plausibility of that event, formal hierarchal Bayesian methods may be used, but this type of detailed uncertainty analysis is beyond the scope of SPAR-H. Further, the use of the CNI distribution does not limit applications solely to the SAPHIRE software. For example, the text discusses the beta function call provided by the EXCEL software and how to use it to represent the CNI distribution. All modern PRA software will, therefore, have the ability to utilize the CNI distribution.	Out of scope.
51. The NRC should consider the use of logistic regression analysis as part of the current approach	NRC	The use of logistic regression analysis in lieu or in addition to the current approach is not within the current project scope. It would require a separate research effort.	Out of scope.
52. In Section 2.7.2, the authors have selected a very interesting set of basic human performance research topics labeled as distributions. The discussions appear to have some relationship to the SPAR-H method. The document could be improved by more clearly linking the basic research models to the assignment of the CNI distribution parameters, and perhaps a set of rules for setting the feasibility of an action under specific accident scenarios.	EPRI	More detailed review and linking of the performance distributions to CNI distribution parameters would be worthwhile. We think that development of a set of rules for setting the feasibility of an action under specific accident scenarios could be explored. We are less certain that either of these activities will substantially contribute to a simplified HRA approach, since it is likely that the relationships will need to be considered in a numerical hierarchical Bayesian framework.	Out of scope.
53. In Section 3, the authors tied the error rate to the ranges used in other methods. An improvement would be to relate the process of selecting a calibration factor to some form of statistically measurable data. In taking this step some baseline tasks should be defined, which can be matched to the current and future PSFs that might be analyzed.	EPRI	This is an interesting suggestion for future improvements. The measurable data would have to be defined along with baseline tasks. We argue to keep the current list of PSFs the same.	Out of scope.
54. A major weakness in the SPAR-H process is relating the assignment of PSF values to a defined functional objective typically analyzed in a PRA. There is little guidance in defining the context of the action or relating the type of PSF to where it best fits in the PRA.	EPRI	The PSF is tied to the HEP as opposed to the functional objective. In obtaining the functional objective, multiple actions with different individual PSF qualities could be involved. Which PSF fits best is scenario and plant specific and we would not try to predefine this for multiple applications. In the SPAR-H approach, the context is referenced through the assignment of PSF levels as opposed to declaring extreme error forcing context or some other type of assignment. This determination would have to be the subject of further study.	Out of scope.

Comment	Source	Response	Scoping
55. The fitness for duty PSF would seem to be a characteristic related more to the responsibility of the individual than of all the crews, and for this reason would be more appropriately modeled as a contributor to the uncertainty distribution rather than to the mean value of the HEP.	EPRI	In event analysis, or in support of SDP, making changes to the uncertainty distribution as opposed to keeping things on a PSF level would make the method overly complex. Fitness for duty may or may not be an individual factor. For example, consider a situation where the entire crew has pulled a double shift or has responded to an emergency requiring a strong physical effort during that same shift, etc.	Out of scope.
56. In the case of PSFs for timing, the authors attempted to simplify the issues by addressing timing in the same way as other PSFs. This can cause some difficulty in integrating with the PRA models, since timing is generally addressed with a generic transient response for groups of scenarios. The HRA assessments then use the timing information to address the details of the response, which involves allocating time to both the cognitive and action elements or to the other elements analyzed. It seems more appropriate to view the HEP evaluation with simultaneous equations, one for the HEP and one for the timing.	EPRI	Time is present in terms of generic transient response for groups of scenarios and then this time is used in HRA assessments, allocated either to diagnosis or action or to both as stated by the reviewer. Viewing or constructing sets of simultaneous equations, one for HEP and one for timing, might refine things but would certainly diverge from the spirit of keeping SPAR-H a usable HRA approach.	Out of scope.
57. The review and evaluation of the method in Section 5 is a very interesting self-evaluation, however it should be subjected to independent benchmarking before drawing any strong conclusions about its capability to meet the criteria in various standards.	EPRI	Agreed. The self evaluation could be expanded and method would benefit by subjecting it to independent benchmarking.	Out of scope.
58. Based on the worksheets and idea that inspectors can fill out the forms, it would seem that they would need some specialized training in the following areas: (i) PRA training on the meaning of accident sequences and role of human actions to be able to define a context for the action (HEP) or integrated result (HFE); (ii) training on the basic elements of HRA and the relationship to the human factors evaluations.	EPRI	SPAR and SPAR-H training is under development. Multiple PRA courses are offered to NRC staff including the various NRC regions.	Out of scope.
59. The worksheets in Appendices A – E address the results as probabilities, where the body of the report indicates that the results are some kind of an index that is used as input to the CNI distribution to prevent probabilities greater than 1.0. The worksheets can produce probabilities greater than 1.0, which violate the fundamental probability theory axioms.	EPRI	The worksheet now contains an adjustment factor that precludes HEPs >1, where the HEP is a best estimate of the mean that is used as an index when input into the CNI. Formerly, the SPAR-H method stated in the case of very high HEPs that the HEP be set directly to 1.0. This heuristic treatment is the same as that for PSFs such as "fitness for duty" wherein if the operator is unfit for duty, or if there is simply not enough time to perform the task, the HEP is 1.0 regardless of any of the other PSFs. The inclusion of an adjustment factor does allow the analyst to produce sufficiently negative HEPs where warranted while staying within the acceptable range for the beta distribution.	See Section 2.7.6 and Appendices A-E.
60. Since the values generated in the worksheets are inputs to the dependency analysis, the dependency results become some mixture of probabilities times indexes, which lose meaning with regard to distributions and axioms of probability.	EPRI	Strictly speaking the PSF levels are scalars and the mean HEP is a probability. There is a precedent in THERP and other methods for multiplying them. In THERP there is also precedent for modifying an HEP that has been adjusted for PSFs through the assignment of levels of dependency (ranging from 0 to complete dependency). In SPAR-H PSFs are multiplied by the mean HEP as if independent. We are aware of this simplified approach creating some difficulties. By highlighting dependency, the analyst forces discussion and hopefully improves the PRA. We argue that a higher HEP can be expected in situations where the there is a linkage to previous failed subevent(s) and that this is a direct means by which to call attention to this fact. For additional insights on the uncertainty treatment, see Comment 50.	Out of scope.

Comment	Source	Response	Scoping
61. The combination of the diagnosis and action probabilities should follow the basic rules of logic.	EPRI	We believe that they do. SPAR does not, however, assign a dependency rating for individual components of a subevent. For example, a task that has diagnosis and action sub components can be treated as a combined failure where either is sufficient to fail the task. A dependency calculation is not performed within the same task. Some reviewers have argued for and against. We do not multiply these two components together simply because it is not an AND (i.e., intersection) gate situation (1E-2 x 1E-3) – for the action to fail, we only need diagnosis to fail OR the action to fail. Either failing to diagnose or failing to take the appropriate action is sufficient in a combined HEP to fail. If the task can be completed without diagnosis, then the diagnosis contribution does not contribute to the failure space represented by the fault tree where the task is modeled and, consequently, would not be factored into the model nor the SPAR-H worksheet.	See Section 2.2.3.
62. Why have different sheets for full power and low power operations when only one number is modified slightly? (a) It would seem more reasonable to address preinitiators and post-initiators in separate sheets. This could be as described in the ASME standard and others that recognize a significant difference between diagnosis (cognition) and actions (execution) and between a response to an event and routine test and maintenance tasks. (b) The current sheets appear to mix the data and processing for these types of events. (c) If the PSF data set of the PSF types vary, then new worksheets should be developed that reflect the research modeling differences between the types of tasks.	EPRI	(a) If it would be beneficial there could be a worksheet check off box that identifies pre- from post initiator activities. We employ a basic human performance model. The people don't change, only the PSFs under those conditions, even on a routine basis. SPAR-H would allow for diagnosis component of maintenance trouble shooting to be accounted for if the analyst so desired. (b) Both the data and the processing are contained on the same sheet to make things easier for analysts in the field. This has been viewed as a positive feature through user feedback. (c) The PSF types are expected to remain the same; problems in mapping to the eight included PSFs can be noted by the analyst in the comment fields. We do not know whether application to extreme events or external events would require new PSFs or new dynamic ranges.	See Section 2.4.4.1.
63. Why have different sheets for diagnosis and action when the PSFs are the same and the variation in the inputs is nearly the same?	EPRI	Using separate sheets accords better human factors, because it reduces the memory burden on the person doing the assessment. The same is true for remembering the different PSF levels as a function of the assignment of diagnosis or action, which is best not left to memory. Data could be collected to evaluate the point further.	See Sections 2.2.1 - 2.2.3.
64. Why address timing independently within an HEP evaluation three separate times (i.e., available time for diagnosis, action, and dependency analysis)?	EPRI	Timing is addressed in this way, because there may be instances where time is relevant for diagnosis but not action , i.e., it could be nominal and there are instances where time does or does not contribute significantly to dependency. If the question is merely an organizational issue, the form could have time addressed in one area of the form; however, there are enough levels to the PSFs that this probably would not reduce work or confusion.	Out of scope.

Comment	Source	Response	Scoping
65. Primary failure modes for diagnosis (mistakes in cue interpretation, etc.) and actions (slips, errors in keeping track of procedural steps, HMI, etc.) the evaluation should address these issues in a more appropriate way. (a) Time dependent response models could be considered. (b) Consider the systematic linking of simultaneous equations to evaluate time as a resource limited PSF case.	EPRI	Identifying failure modes themselves (assignment of slips, lapses, or mistakes) is not made in the worksheet per se. The SPAR-H approach makes it the analyst's obligation to declare such information in part of the HRA write up or embed such information as part of the error description or as part of PSF information. Determining which error mode is more likely is part of the HRA search process and PRA scenario development effort. (a) Development of time dependent response models or a series of such models would serve to complicate the analysis and reliability inherent in applying the worksheets. The models would have to be developed and evaluated against a variety of conditions and scenarios. (b) Equation development and validation is not part of the scope of the present effort.	Out of scope.
66. Nomenclature issue. SPAR-H does not take advantage of the ASME definitions for the assessment. HEPs are single evaluations of a diagnosis/action before the dependency assessment. HFEs are integrated assessments made after the dependency assessment that represents the overall failure to manage the sequence for post initiator actions. Errors with subscripts were noted.	EPRI	The language among HRA methods is not consistent. The INL has used HEPs, nominal HEPS and conditional HEPs to represent differences in the level of analysis, consideration of PSFs, and dependency. For example, unsafe acts are used by some analysts and can be the result of single or multiple HEPs. Only a portion of unsafe acts end up as HFEs. And the mapping of UAs to HFEs can be one to one or many to many. The adoption of a common language and resolution of differences in terminology is a worthwhile goal. The errors with worksheet subscripts have been noted and corrected.	See Appendices A – E.
67. It is a good idea to address the dependency when two separate tasks are involved in the same accident sequence. The application of Swain's dependency formulations appears to be misapplied. The way that human actions appear in the same accident sequence is through AND gates in the same model. If they go through OR gates, then they appear in separate sequences and no dependency assessment is needed. Recheck the formulation of dependency in Appendix D and some aspects of calculation.	EPRI	The dependency calculation is typically used for an AND gate situation. However, we could conceive of how poor procedures could imply a propensity for a failure that wasn't present and inhibit good diagnosis (HEP1), call out an incorrect action (HEP2), and failure on a second action (HEP3) is now increased because of the difficulty caused by the failure on the first action. There is a linkage between 1 and 2, and a common linkage among all three by virtue of the procedure's influence on performance. The dependency table on the worksheets has been modified to make determinations easier and more explicit.	See Appendix D.
68. What is missing from Appendix F is a comparison to the base case conditions that are assigned to the mean HEP value. This would be needed to illustrate what to look for in evaluating a PSF change.	EPRI	Such a comparison is not part of the analysis performed in support of documenting the method for this report.	Out of scope.
69. Provide an intra-dependency PSF matrix whenever multiple PSFs are applied.	EPRI	There have been separate suggestions along these lines. However, the work has not been performed on how to implement such a matrix, qualitatively or quantitatively. As such, it remains beyond the scope of this report.	Out of scope.
70. Existing industry methods such as EPRI CDBTM (EPRI TR-100259) and THERP (NUREG-1278) are not recognized as complete HRA methods.	EPRI	This has been adjusted in the body of the report.	See Section 2.4.

Comment	Source	Response	Scoping
71. The SPAR-H process does not specify how HFEs consisting of multiple tasks are to be addressed.	EPRI	SPAR-H suggests that the HFEs be decomposed to the level of tasks as appropriate. Some applications are performed at a higher level than others. The main guidance is that the analyst be consistent with the level of decomposition. It may be possible to develop rules regarding the number of subtasks or tasks that could or should be combined. This could be an area for further research. In general, determining the correct level of decomposition is not a criticism or challenge unique to SPAR-H. Some analysts are more holistic and others atomistic. If an analyst does use rules for combining sub tasks or sub events, s/he should make explicit those rules as part of the HRA analysis effort.	Out of scope.
72. Table 2-3 provides THERP multipliers, which are not generally presented in THERP as multipliers. This should be indicated in the text.	EPRI	Yes, these multipliers were determined from our review of THERP and an annotation has been added to the report.	See Table 2-3.
73. The interpretation that THERP provides a multiplier of 50 in the absence of procedures is incorrect. THERP provides an HEP of 0.05 for "when written procedures are available and should be used but are not used." The multiplier is inferred if assuming a base HEP of 1E-03, which is the Action HEP in SPAR-H. However, if the Diagnosis HEP of 1E-02 in SPAR-H is assumed, then this multiplier would only be 5.	EPRI	In part, the reviewer's comment assumes that HEP for action tasks where there is an absence of procedures should be 0.05 and suggests that a diagnosis task's HEP = 0.05 should also exist. In that situation, the latter has a multiplier of 50 and the former a multiplier of 5. That has not been our approach. The reviewer is correct that 1.0E-3 with a factor of 50 yields 0.05, and this interpretation can be traced back to NUREG-1278 and actually applies to errors regarding the omission of an item when procedures are not used. However, our interpretation of Swain for the diagnosis case is that diagnosis in the absence of procedures yields an HEP of 0.5 (50 x 1E-2 = 0.5), hence the multiplier of 50 still holds. This is our interpretation; Swain provides no guidance for a diagnosis situation in the absence of procedures. We reviewed ASEP, and in Tables 7.1 and 8.1 it appears that actions without procedures have an HEP = 1.0. We prefer the THERP version. Diagnosis in ASEP uses time available calculation for diagnosis then adjusted for procedures. For diagnostic situations without the written procedures, the HEP is assigned the value HEP = 1.0 and then, according to the guidance, the HRA is stopped. In our judgment, ASEP appears overly conservative. The use of the multiplier of 50 that we selected was an engineering judgment on our part that softened the available ASEP value.	See Table 2-3.
74. SPAR-H considers "time available" for diagnosis and action separately. The time available is usually obtained from physical transient data and applies to diagnosis and action. Will it be obvious to the user that diagnosis time will decrease action time and vice versa?	EPRI	This is a good point, and we have incorporated this into the instructions.	See Section 2.4.4.

Comment	Source	Response	Scoping
75. The SPAR-H method discounts the lognormal distribution on the basis that it could produce an HEP > 1, and it adopts the beta distribution instead. The beta distribution may be an equally valid approach, but the lognormal is widely used in industry, not only in HRA but for component failure rates as well.	EPRI	Our use of the beta distribution was an attempt to increase the precision of the math and produce means and upper and lower bounds that would easily support PRA calculations available in software workstations such as SAPHIRE. This addresses a number of complaints regarding not only SPAR-H but other methods employing lognormal distribution of error (e.g., THERP, etc). Additionally, some of the work on human performance in the behavioral sciences literature suggests that many other distributions are better descriptors of human behavior than is the lognormal. For additional clarification on why the INL did not use ad hoc methods such as lognormal distributions see Comment 50.	See Section 2.7.6.
76. The use of Fitness for Duty as a PSF may be onerous. Based on discussion, this would, for example, pertain to different shifts having different failure rates. This could imply that the HRA needs to take into account different shifts. Given the inherent uncertainty in HRA, the additional effort to model shifts would not be justified by the value added.	EPRI	This concern may be true for prospective analysis, which in the use of this PSF may be more difficult. However, in SPAR event analysis, this variable affords the analyst the opportunity to account for fitness of the crew as it figured in the event. Usually, one or two crews at most are involved, and data are present.	See Section 2.4.4.7.
77. The SPAR-H report discusses several issues of timing. There is a systematic problem in that the PSF is set on the time available to complete an action before some irreversible, undesirable event occurs to the reactor. This time window is used to set the stress PSF for the operator. The problem is that, for this PSF, the operator is not always aware of the time available to diagnose or perform an action. The operator will have a perceived time window, which may or may not be consistent with reality.	EPRI	This is an interesting discussion. If the analyst has strong evidence to believe that the crew has inaccurate or imprecise knowledge regarding the time available before events cannot be corrected, this should be recognized. It is difficult to determine the operator's internal state. It could be due to training/experience or misleading indication, e.g., tank level. We would adjust these two PSFs as opposed to time available. The rate would be based upon the time available (its ratio to the time required) and these other PSFs.	See Section 2.4.4.1.
78. For the diagnosis PSF, the first timing demarcation is set at 20 minutes and described as "barely adequate." The basis for selection of 20 minutes is not indicated or justified. Note, having 22 minutes available rather than 20 minutes, changes the PSF from 10 to 1. (Also see Comments 2, 8, 14, and 30)	EPRI	The timing demarcation was interpreted from THERP, which is the basis. However, we have taken this comment to heart; the PSF assignment now takes into account two factors; relative time and absolute time. We do reduce the HEP for "at-power" situations where there is extra or expansive time available, beyond a certain minimum corresponding to interpretation of the THERP diagnosis curves. The data that are available supports the notion of thresholds. Where such information has not been available we have relied upon relative times as a means of better approximating the expected HEP.	See Section 2.4.4.2.
79. Table 3-5 is a comparison of the differences between power operation and shutdown operation. It is biased from the perspective of a PRA analyst who is unfamiliar with shutdown PRA and more comfortable with power PRA. The table is used to change the method of PSF assignment for shutdown PRA. The comment here is that differences between power and shutdown operation are not substantial differences and do not form a basis for changing the PSF scheme.	EPRI	The table is based upon input from a variety of sources including individuals familiar with LP/SD situations. Potential uses of systems such as RWST gravity drain, spent fuel pool cooling, reflux boiling and fill and spill will be considered as potential future modifications to the table in question. The authors will also make changes that decrease the likelihood that users will be led to perceive LP/SD as abnormal as opposed to less frequently performed evolutions.	See Table 3-5.
80. The SPAR-H method does not provide sufficiently detailed criteria for the HRA analyst to select the appropriate category of PSF quality. This will lead to different analysts assigning different PSF levels and getting different answers, with no way to resolve the differences.	EPRI	In 1999 some inter-rater reliability work with the method was performed with positive results. In 1999 and in 2000 additional user comments were employed to enhance the definitions. We see value in obtaining reliability ratings beyond the national lab and NRC HQ as a means of further pedigree for the method.	Out of scope.

Comment	Source	Response	Scoping
81. The NRC should work to establish reliability measures for SPAR-H beyond the national laboratory and a limited number of staff.	ACRS	The idea to extend reliability measures to the community at large is a good one. However, this program has always operated on iterative feedback. All users have been and continue to be encouraged to make the program aware of problems in applying the procedures or any aspects of the method. This has been the approach taken for a number of years and has proved to be quite valuable in improving the method and standardizing the current approach.	Out of scope.
82. Why does the NRC need more than one HRA method?	ACRS	SPAR-H is a simplified HRA method that is intended for use in quick turnaround event analysis, building plant models, and by inspectors to support the NRC significance determination process (SDP) process. SPAR-H can highlight issues or problems that then can be addressed by more labor intensive approaches such as NRC ATHEANA or others in industry that have a recognized approach in determining highly specific contexts in which the likelihood for errors of commission is heightened. In forcing consistency among analysts with limited training, SPAR-H uses nominal rates to account for a mixture of omissions and commissions. It also uses a basic human performance model that does not differentiate between latent and active human failure events, leaving that to the analyst's error description and PSF evaluation(s). SPAR-H is also not geared to identify unique error causal mechanisms as is the case with some second-generation HRA methods.	See Section 2.4.1.
83. Why is there a fixed number of PSFs when other methods have a different number or in some cases seem to have an unlimited number depending upon what an analyst may discover during the HRA process.	ACRS	We believe that the eight PSFs that SPAR-H uses in quantification will cover the majority of the situations that the analyst building plant models or performing event analysis will need. The list is fixed to force consistency in the PSFs considered by analysts every time the method is used. We also believe that most of the PSFs that other methods may use that are not present in SPAR-H can be mapped to existing PSFs. For example, corrective action program failures, or design inadequacies can be mapped to the SPAR-H work processes PSF.	See Sections 2.4.1 and 2.4.3.
84. Are PSFs assumed to be independent? Are we double counting somewhere? For example, stress can be related to the time available; in others the impact of the task can be so overwhelming that having extra time may not really reduce the stress associated with task performance. INL should consider having a warning or at least sensitizing the user to the potential for overlap among PSFs.	ACRS	PSFs are not independent. The authors have included cautionary statements in the text, per the suggestion to sensitize users. The adjustment factor can reduce double counting to some extent but it is based upon mathematics as opposed to theory why some PSFs might be more highly related than others. Finally, in Appendix G there are some findings regarding the relationship among PSFs, and the Discussion Section of the report calls for the need for the HRA community to provide research in this area.	See Section 2.5.
85. It appears that the message from second generation HRA is that context matters. Do you agree, and is this represented in some way in SPAR-H?	ACRS	Generally speaking, the message from second generation HRA is that context matters. The assignment of context requires some level of expert judgment. Context in SPAR-H is acknowledged through the assignment of PSF levels for diagnosis and action task types and through dependency assignment. SPAR- H does not focus on context-driven search schemes for error identification but instead provides some references for the less trained analyst where he or she can go to support the error identification and modeling process.	See Section 5.2.
86. There is a fundamental difference between the nominal condition or having insufficient information, making it difficult for the analyst to know whether the nominal or some other PSF level applies. Additionally, in terms of uncertainty, it would appear that these are two different situations as well.	NRC Staff	Agreed. An additional PSF level for insufficient information has been added to the worksheets. We agree that different types of uncertainty and/or degrees of uncertainty exist between these situations.	See Appendices A – E.

Comment	Source	Response	Scoping
87. The method and presentation would benefit if more examples of application, especially those involving multiple PSFs and simultaneous conditions could be developed and reviewed in the report. Particularly, more examples regarding PSF assignment during LP/SD would be of benefit to analysts.	NRC	The current report documents the current state of method development including the calculation approach and definition of terms. We agree that it would be good to develop additional examples to help ensure consistency and understanding among analysts and applications of the method. The extent to which simultaneous conditions change the interaction among PSFs and performance is a challenge to the field of HRA.	Out of scope.
88. Unlike other PSF situations evaluated by the analyst where positive influences can reduce the base HEP, there seems to be no credit given or allowance made for situations where an analyst may wish to assign a positive influence associated with stress. This seems to be in disagreement with information presented previously, i.e., in the INL review of human performance distributions, where there seems to be evidence that stress can be a motivating force and that optimum performance is associated with a certain degree of stress or arousal.	INL	SPAR-H does not account for the influence of positive dependence. The same is true for the positive effects of stress. While it is factual that there are data that some level of stress is associated with positive performance, the SPAR-H analyst does not evaluate the influence of stress in this way. As a beginning point, we assume (unless otherwise indicated by a negative fitness for duty selection) that we are dealing with a reasonably alert and motivated operator. This assumes a positive influence for stress and arousal that is accounted for in the nominal value for stress. For our purposes, the stress and stressors supporting positive operator or crew performance are assumed to be addressed when the analyst selects the nominal stress category.	See Section 2.4.4.2.
89. The current instructions associated with symptom based procedures are disturbing in that poor symptom based procedures would still reduce the nominal HEP. Please review.	INL	We agree. If the symptom based procedure is found to be inaccurate or awkwardly constructed, then the procedures PSF should be negatively rated. Section 2.4.4.7 has been modified to incorporate this suggestion.	See Section 2.4.4.5.

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10. SUPPLEMENTARY NOTES
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11. ABSTRACT *(200 words or less)*

In support of the Accident Sequence Precursor Program, (ASP), the U.S. Nuclear Regulatory Commission (NRC) in conjunction with the Idaho National Laboratory (INL), in 1994 developed the Accident Sequence Precursor Standardized Plant Analysis Risk Model (ASP/SPAR) human reliability analysis (HRA) method, which was used in the development of nuclear power plant (NPP) models. Based on experience gained in field-testing, this method was updated in 1999 and renamed SPAR-H, for Standardized Plant Analysis Risk-Human Reliability Analysis method. In 2003, to enhance the general utility of the SPAR-H method, and to make it more widely available, the method was updated and reviewed for its applicability to low-power and shutdown applications. This document presents the current version of the SPAR-H method, along with guidance, definitions, improvements in representing uncertainty, and increased detail regarding dependency assignment for HEP calculations. This report also contains comparisons between this and other contemporary HRA approaches and findings specific to application of the method to low power and shutdown events.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*

Human reliability analysis (HRA), probabilistic risk assessment (PRA), standardized plant analysis risk (SPAR), human performance, accident sequence precursor (ASP)

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