UNITED STATES
NUCLEAR REGULATORY COMMISSION

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May 13, 2003

EA-03-016

Craig G. Anderson, Vice President,
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SUBJECT: ARKANSAS NUCLEAR ONE - NRC TRIENNIAL FIRE PROTECTION INSPECTION REPORT 50-313/01-06; 50-368/01-06 - SUPPLEMENTAL RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

Dear Mr. Anderson:

In Attachment 1 of your letter dated April 2, 2003, you requested additional information pertaining to the potentially greater than Green finding identified in the subject NRC inspection report. In a letter dated April 11, 2003, Region IV provided information addressing your request. In a subsequent telephone conversation, Mike Cooper of your staff requested a copy of the reference document used by Troy Pruett of NRC Region IV to evaluate the risk contribution from human reliability. The enclosure to this document is the document you requested. Please note that the NRC office of Nuclear Regulatory Research plans to release this same document shortly to the public, including licensees.

In accordance with 10 CFR 2.790 of the NRC's "Rules of Practice," a copy of this letter and its enclosures will be available electronically for public inspection in the NRC Public Document Room or from the Publicly Available Records (PARS) component of NRC's document system (ADAMS). ADAMS is accessible from the NRC Web site at http://www.nrc.gov/reading-rm/adams.html (the Public Electronic Reading Room).

If you have any further questions, you may contact me at 817-860-8185.

Sincerely,

/RA/
Charles S. Marschall, Chief
Engineering and Maintenance Branch
Division of Reactor Safety

Dockets: 50-313; 50-368
Licenses: DPR-51; NPF-6

Enclosures:
1. Fire Modeling of Fire Zone 98-J, Emergency Diesel Generator Corridor and 99-M, North Electrical Switchgear Room, Arkansas Nuclear One - Unit 1

2. Phase 3 SDP Analysis: Arkansas Nuclear One, Unit 1

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**ENCLOSURE**

**NUREG/CR-xxxxx**

**INEEL/EXT-02-10307**

# SPAR-H Method

**Idaho National Engineering and Environmental Laboratory**

**U.S. Nuclear Regulatory Commission**
**Office of Nuclear Regulatory Research**
**Washington, DC 20555-0001**

NUREG/CR-XXXX
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# SPAR-H Method

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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 Engineering and Environmental Laboratory (INEEL), in 1994 developed the Accident Sequence Precursor Standardized Plant Analysis Risk Model (ASP/SPAR) human reliability analysis (HRA) method used in the development of plant models. Based on experience gained in field-testing, this method was updated in 1999. 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 (SDP), developing an integrated risk-informed performance measure in support of the reactor oversight process (ROP), and screening and analyzing operating experience data in a systematic manner to identify events/conditions that are precursors to severe accident sequences. As a result of implementation by staff analysts, and other experience at the INEEL in applying the method in HRAs, a number of needed improvements to definitions, terms, and concepts were identified. In 2002, to enhance the general utility of the Standardized Plant Analysis Risk Human Reliability Analysis (SPAR-H) method, and to make it more widely available, the method was updated and reviewed for its applicability to low power and shutdown (LP/SD) applications. During this review, an approach to uncertainty representation was outlined based upon the beta distribution and additional detail for the SPAR-H method regarding human error probability (HEP) dependency assignment was made available.

This document presents the current version of the SPAR-H method, along with guidance, definitions, representing uncertainty, and instructions regarding dependency assessment for HEP calculations. This report also contains comparisons between this and other contemporary HRA approaches and findings specific to application of the method to LP/SD events.

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# EXECUTIVE SUMMARY

Human performance has been a contributor to incidents and accidents in many industries. Recently, the role of human error was documented in a number of significant 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: (i) performing safety studies such as probabilistic risk analysis (PRA); (ii) helping to risk-inform the oversight inspection process; (iii) reviewing special issues; and (iv) helping to risk-inform regulation. HRA has also been used to support the development of plant-specific PRA models.

This report presents a simplified HRA method for predicting the human error 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 the development of plant-specific PRA models for the United States Nuclear Regulatory Commission (NRC), Office of Nuclear Regulatory Research (RES) and recently has been used to help support the Office of Nuclear Reactor Regulation (NRR) Reactor Oversight Process (ROP). The SPAR-H method is also applicable to pre-initiator events.

Based upon 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 upon 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.

The SPAR-H method is built upon 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, 1996). This human performance model is presented in Figure 1. In 1999, further research identified eight performance shaping factors (PSFs) deemed most capable of influencing human performance. These PSFs are accounted for in the SPAR-H quantification process. These factors include:

- Available time
- Stress
- Experience and training
- Complexity
- Ergonomics (human-machine interface)
- Procedures
- Fitness for Duty and
- 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, the positive influence of PSFs can *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, and that this improves human reliability. Figure 2 shows this relationship and the influence of the PSF (X-axis) on mean human error probability (HEP) values (the Y-axis).

Formerly, the SPAR-H method addressed dependency. Dependency in this case, means that the influence of one human error on

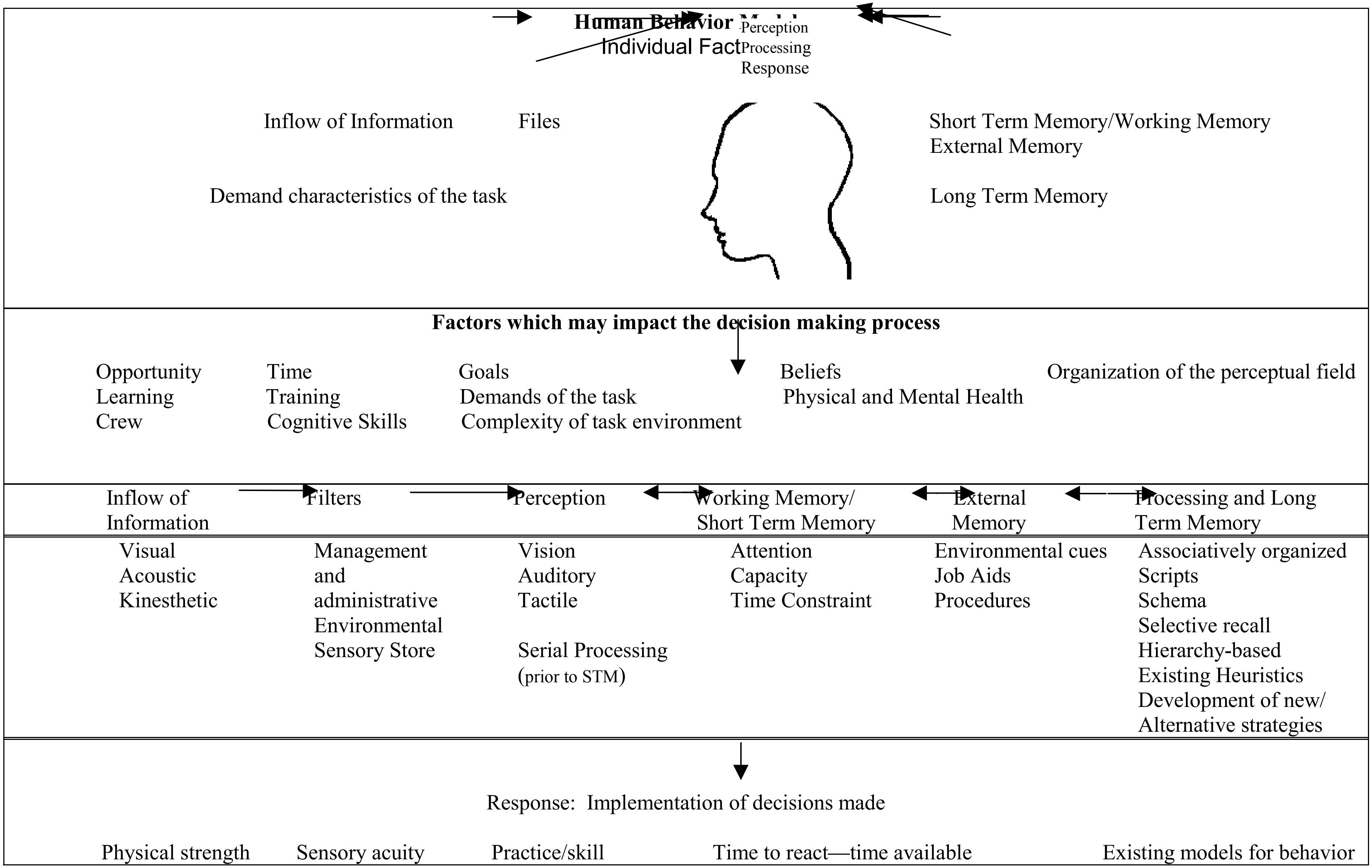


Figure EX-1. Human behavior model.

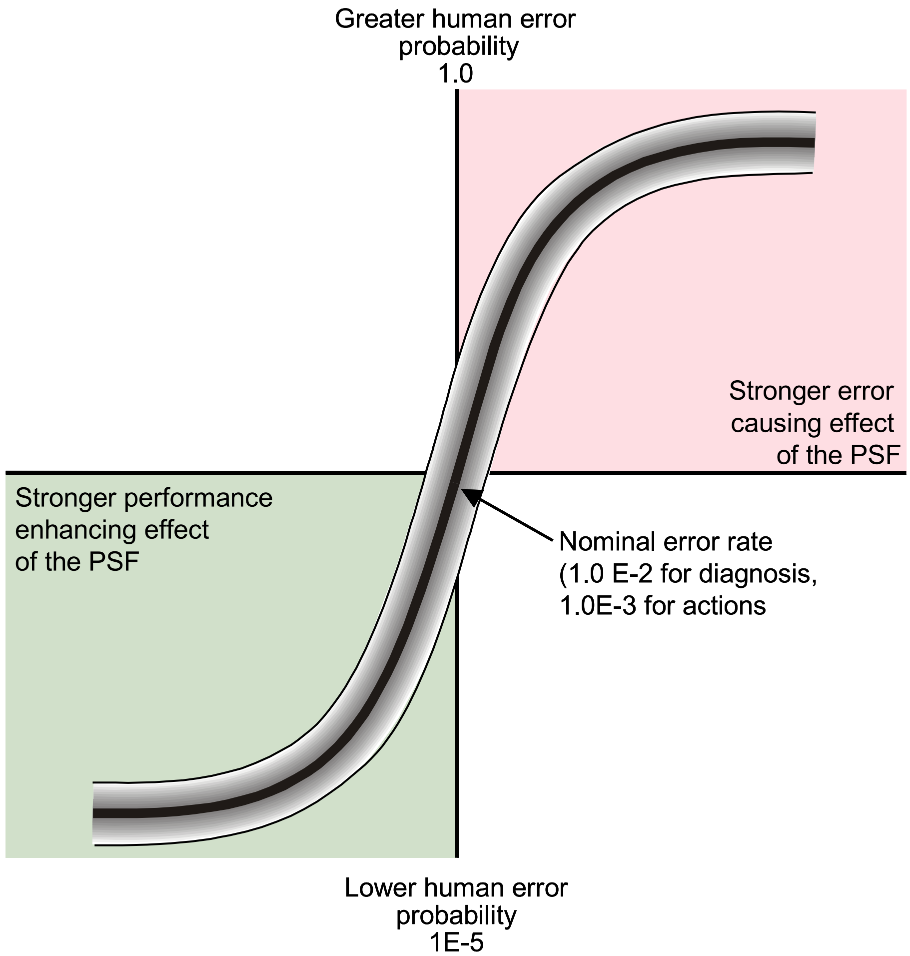


Figure EX-2. Idealized mean HEP as a function of PSF influence.

subsequent human explicitly errors is accounted for by the model. Although the literature on dependency among human errors is limited, the INEEL review concluded that the following combinations of factors contribute 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 piece of equipment must be the same or located within the same relatively restricted area, such as the same panel)
- Lack of additional cues [additional cues exist if there is a specific procedural call out or a different procedure is used, or additional alarm(s) or display(s) are present]
- Close succession of the next action/reaction (from within seconds to a few minutes).

Various combinations of these factors were considered and given a rating based on their combined effect on dependency in error propagation. 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 for failure on Task B, given failure on Task A provided in NUREG/CR-1278 (Swain and Guttman, 1983), but offers additional guidance for dependency assignment.

Once dependency has been determined to be present, moderate-to-high dependency can 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 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 recovered error.

The SPAR-H method may be applied on a task level (as is the case when developing SPAR models for low power/shutdown [LP/SD] or full power), or on a subtask level when building HRA event trees, (i.e., performing more detailed analysis). 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. However, when building HRA event trees, diagnosis and action are not combined in a single HEP.

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 the IEEE Standard P1082 for HRA (1997), ASME Standard for PRA (ASME STD-RA-2002), and the EPRI Systematic Human Action Reliability Procedure (Hannaman and Spurgin, 1985). When applied to situations other than SPAR model building or screening situations, the comprehensive HRA search strategies found in NUREG/CR-1624 (Sorester et al., 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 simplified 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 has the advantage that probabilities calculated with this approach range from 0 to 1. Use of a constrained non-informative prior, based upon Atwood's work (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 upon human performance.

A major component of the SPAR-H method presented in this report is the SPAR-H Worksheet presented in Appendix A. The method for filling out these worksheets is described below. Note that the process differs slightly depending upon 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 model development, the major focus for the HRA method development 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 must decide whether the actions specified involve diagnosis or are purely action-based. There are some instances where action and diagnosis are intertwined and indiscernible, and others where a step in SPAR events may represent a task with many underlying subtasks. In such instances, the basic event in the PRA model represents both diagnosis and action. If a step involves both action and diagnosis, two worksheets corresponding to action and diagnosis are filled out. Guidance is provided for determining the composite failure rate.

When developing the basic SPAR model, three of the eight PSFs are immediately evaluated: the

time available, stress, and complexity. The remaining five PSFs (experience, procedures, ergonomics, fitness for duty, and work processes), are generally rated nominal, because they are usually event- 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 definitions. This dependency among failures is then used to support quantification of the final HEP.

The positive influence of dependence has not been investigated and therefore is not part of the SPAR-H method.

## Discussion

The SPAR-H method was designed to be straightforward and easy to apply. It is based on a human information-processing model of human performance and other results from human performance studies published in the behavioral sciences literature. This simplified HRA approach contains a number of significant features, including calibration of its base failure rates and 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 removes problems experienced in earlier versions when applying error factor approaches.

The 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. The method does not differentiate between active and latent failures. Identification and modeling of active and latent failures is the decision of the analyst. It is thought that the same PSFs and base failure rates are generally applicable to both types of error. The base error rates contained in the worksheets for actions and diagnosis include omission and commission types of error. The explicit representation of omission versus commission is an issue left to the analyst and is part of the error identification and modeling activities of HRA.

The tendency for omissions or commissions 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.

The explicit incorporation of work processes in PRA/HRA is relatively new. For an example discussion of organization factors with emphasis on work practices, see Apostolakis (1999). The range of effect used 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 range in SPAR-H is within the bounds suggested by these methods.

Traditionally, accounting for the influence of multiple shaping factors with various 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. The authors feel that analyst 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 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.

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# ACRONYMS

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|---|---|
| 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 |
| INEEL | Idaho National Engineering and Environmental 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 & 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 |
| Pw/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 underwater breathing apparatus |
| SD | Shutdown |
| SG | Steam generator |
| SGTR | Steam generator tube rupture |

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|---|---|---|---|
| SHARP | Systematic Human Action Reliability Procedure | TH | Thermal hydraulics |
| SLIM | Success Likelihood Index Method | THERP | Technique for Human Error Rate Prediction |
| SPAR | Standardized plant analysis risk | TLX | Task Load Index |
| SRV | Safety relief valve | TOC | Technical Operations Center |
| SS | Shift supervisor | TRC | Time-reliability curve |
| STD | Standard | TS | Technical Specifications |
| SM | Secondary memory | TSC | Technical Support Center |
| STM | Short-term memory | UA | Unsafe acts |
| | | UB | Upper bound |

# GLOSSARY

**ASP SPAR (1994)—**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 "basic event" is used in this report to describe a component failure, loss of function, unavailability or failed human action in a SPAR model fault tree. An example of a basic event might be "Operator fails to throttle 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 actions and diagnosis as the major type tasks and various error types are distinguished.

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

**Event—**An "event" is a high level generic term encompassing a non-normal occurrence at a nuclear power plant (or other facility).

**Human error—**The term "human error" as used in this report refers to 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.

**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.

**Initiating Event—**An "initiating event" in the SPAR model terminology is one of the high-level scenarios under study, (e.g., steam generator tube rupture, loss of feed water, loss of offsite power, etc).

**Low power and shutdown (LP/SD)**—Refers to a set of nuclear power plant (NPP) operating modes and is 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 PWRs there are 6 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 BWR, there are 5 operating modes. Modes 3, 4, and 5 refer to hot shutdown, cold shutdown and refueling, respectively.

**SPAR-H method (1999)**—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 (2002)**—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, full power and LP/SD considerations made explicit.

**Subtask**—The term "subtask" in this report refers to a human action at a level lower than a task (i.e., basic event) level.

**Task**—The word "task" in this report often refers to the human action(s) described in a SPAR model basic event (e.g., failure to recover 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.

# 1. INTRODUCTION

## 1.1 Overview

The Standardized Plant Analysis Risk human reliability analysis (SPAR-H) method is a simplified human reliability analysis (HRA) approach intended to be used in conjunction with the development of SPAR models. The language included in this document often refers to aspects of SPAR models such as initiating events and basic events—terms common to Probabilistic Risk Assessment (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 4.1.3.

The SPAR-H method contains three requirements integral to HRA: error identification, error modeling (representation), and quantification. Guidance for satisfying these requirements may be formed in IEEE STD P1082 (1997) or ASME STD for practice of PRA (ASME RA-STD-2002). It is assumed 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, so that there is a context regarding how these estimates are to be combined and their effects interpreted. Modifying failure probabilities based upon 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 Engineering & Environmental Laboratory (INEEL) undertook a review in 1994, during which, 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 INEEL 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.

In 1999, the field of HRA 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 other 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 upon error factors, analysts could routinely produce upper bound probabilities greater than 1 when modeling strongly negative performance shaping factors (PSFs). This problem was not unique to performing SPAR-H. Although HRA analysts have worked around this problem for 20 years, the INEEL 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 (INEEL, 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 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 offset risk, including the human contribution. 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 author’s 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 upon 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 pre-initiating actions, initiating event-related actions, and post initiating 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 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 rely upon time as the primary determinant of performance, but rather treats time as one of a number of important shaping factors influencing human performance.

## 1.4 Guidance in Performing HRA

A number of guidance documents are available that can be used to support the SPAR-H method. These include 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 ASME Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications (ASME RA-STD-2002). The IEEE recommended practice for conducting HRA (IEEE 1574, draft) is under development and when completed will also provide a framework for conducting HRA.

It is assumed 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, 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.

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

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 a summary and discussion of the approach and compares this HRA method against some of the criteria for HRA as defined by the new ASME PRA Standard, and the NASA PRA Guide for Managers (Stamatelatos and Dezfuli, 2002). Last, this report contrasts the SPARA-H method against criteria developed by the authors for review of HRA methods (Gertman and Blackman, 1994).

# 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, 1980; 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 comprising the basic elements of this model also come from the literature surrounding the development and testing of general information processing models of human performance.

Figure 2-1 presents the SPAR-H basic information-processing model. It shows the key aspects of an information-processing model of human performance that reflects psychological research. The purpose of beginning with this model is to account for and integrate the factors key to human performance when performing SPAR-H analysis.

Review of the behavioral sciences literature and other models suggests eight summary operational factors, or PSFs, that we considered important to nuclear power plant operation. These operational factors can be directly associated with the model of human performance. 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.

*The role of work processes*. Work processes are present in the model described above in terms of the organizational parameters of the model and are present in the "work processes" PSF included in the SPAR-H worksheets (Appendix A). 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 (NUREG/CR-6753 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%).

Recently, the root cause analysis report for Davis Besse (Gertman et al, 2002) identified a number of work process or organizational factors that may have contributed to a reactor pressure vessel head corrosion incident. Implicated were a flawed boric acid corrosion control program, and subsequent failures such as lack of written evaluations, inadequate implementation of the 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 either inadequate work processes or inadequate implementation of work processes.

For a more in-depth review and approach to work process evaluation, see Weil and Apostolakis (2001).

## 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 problematic for others.

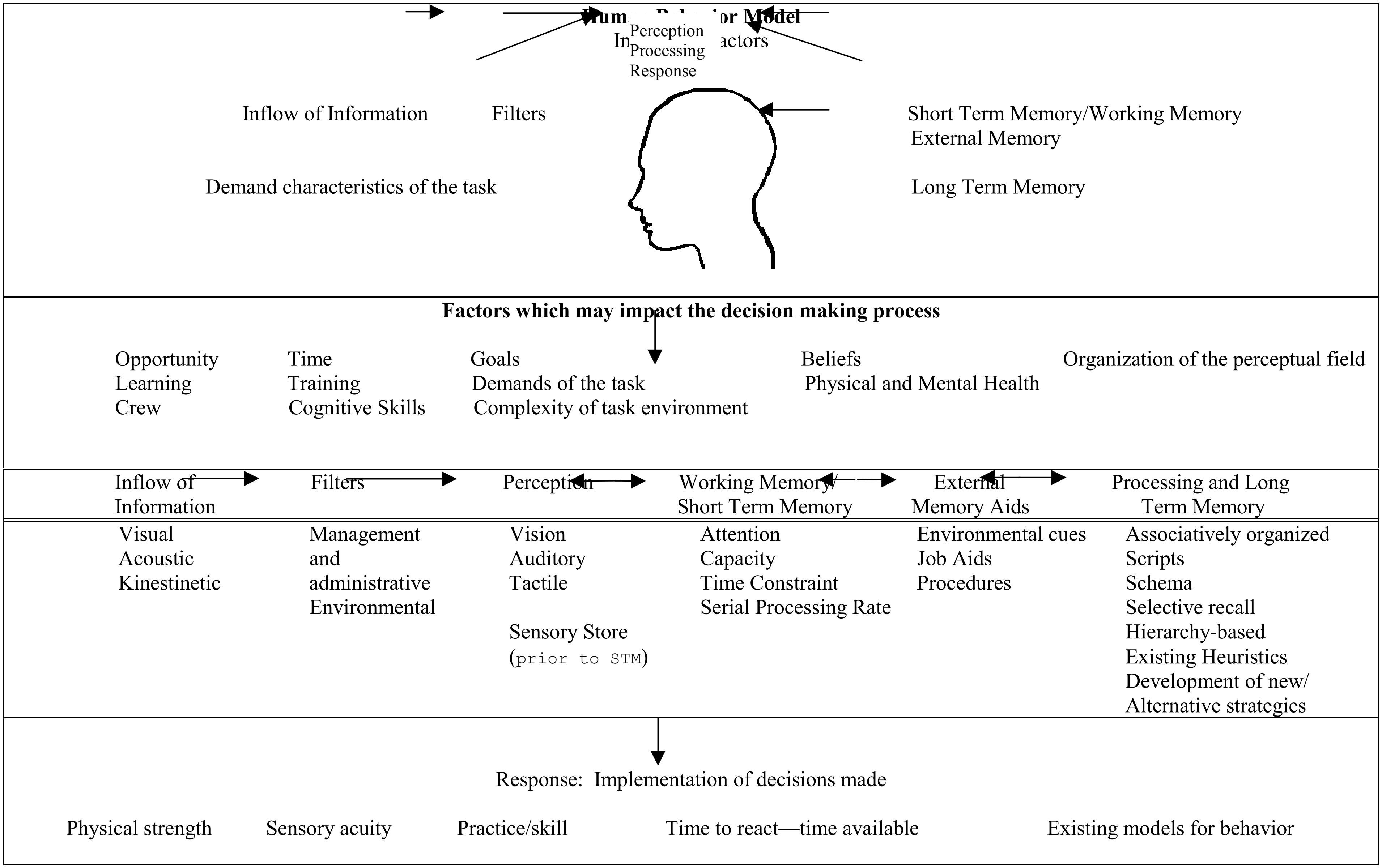


Figure 2-1. Human performance model.

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 Term Memory/ Short Term Memory | Processing and LTM | Response |
|---|---|---|---|
| Human sensory limits[2,5,7]<br><br>Modality[6,5] (verbal, visual, motion)<br>• echoic<br>• iconic<br>• kinesthetic<br><br>Interference[6,5,4,7] (signal to noise ratio)<br><br>Cultural[8] is perceived as immediately important) | Limited capacity[5]<br>• serial processing<br>• only good for a short time[2,3,5,4] (20 seconds)<br><br>Right amount of attention[2,3,4,5,7] required<br><br>Rehearsal[2,3,5,7]<br>Physical and mental health[7] | Training[4] (models, problem solving, behaviors)<br>• learning<br><br>Experience[4] (models, problem solving, behaviors)<br>• learning<br><br>Culture [8] (what cues are afforded the most attention)<br>• learning<br><br>Intelligence/cognitive skills[3,4,1,5,7] (decision making, problem solving)<br><br>Interference factors [6,2,3,7] (distraction)<br><br>Available time [1,3]<br><br>Physical and mental health [7] | Training (actions) [4]<br>• existing models of behavior<br>• practice and skill<br><br>Experience[4] (actions)<br>• practice and skill<br>• existing models of behavior<br><br>Proper controls available[6]<br><br>Human action limits[6,7] (physical strength and sensory acuity)<br><br>Ergonomics of controls[6,3] complexity<br><br>Environmental degradation[2,3,6]<br><br>Time to react versus time available[1] |

Summary Level Factors

1. Available time
2. Stress
3. Complexity
4. Experience and training
5. Procedures(including job aids)
6. Ergonomics
7. Fitness for Duty
8. Work processes

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.

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 is often used in HRA (most applications also classify actions as pre-initiator, initiator-related, or post-initiator).

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 quantification. When using this approach, activities such as planning, intra-team communication, or resource allocations during event progression are included in diagnosis.

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

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 should employ a complete HRA method. Complete methods include: a technique for human event analysis (ATHEANA), (Forester et al., 2001); cognitive reliability evaluation and analysis method (CREAM), (Hollnagel, 1994); Methode d' Evaluation del' la Reaslisation des Missions Operateur pour la Surete' (MERMOS), (Le Bott et al, 1998); or the connectionism approach to human reliability, (CAHR) (Strater, 2000). 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 task consisting of several actions and decisions (such as is often the case with SPAR models), both diagnosis and action tasks and their respective worksheets apply. Tasks that are proceduralized actions not requiring diagnosis are evaluated on the action task worksheets.

In comparing the way the 1994 ASP HRA method PSFs, the revised 2002 SPAR-H method, and other HRA methods treat PSFs, we considered the differences between mental processes and the physical response, and whether a given PSF specifically addressed one or both aspects of these activities.

The result of the PSF comparisons, matched to either action or diagnosis, was a list of the 1994 ASP HRA method PSFs and a comparable list of PSFs from the other methods and sources. If PSFs from the 1994 ASP HRA method and the comparison method differed, they were noted. The team reviewed these differences and used this information to develop the SPAR-H method PSFs and 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 2002 SPAR-H method development process, the base error types from the other methods were compared with the 1994 ASP HRA method error types. This comparison was considerably easier than the PSF matching. 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 version, the discussion of omission and commission within the HRA community for describing error has slowly moved toward terms such as slips, lapses, and mistakes. This, in part, is due to new perspectives, intuitively appealing, that there is an important difference between slips and mistakes, the two frequently discussed errors of commission. The first type of commission is termed a slip (right intention, wrong execution) and the second is called a mistake (having a

wrong impression of what to do coupled with an improper action or decision). 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.

## 2.4 PSFs

Many, if not most, HRA methods use PSF information in the estimation of HEPs. In general, the use of PSFs attempts to enhance the degree of realism present in HRA. 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.

In 1999, changes to the ASP 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 that indicated:

- “The raters don’t understand the processing/response dichotomy”
- “Most of the other HRA methods recognize separate diagnosis and action error types” and
- “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, complexity, experience and training, procedures, ergonomics, fitness for duty, and work processes. These same PSFs are present in the 2002 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 showed the comparison of PSFs and their weight multipliers for SPAR-H method PSFs versus PSFs and multipliers for other contemporary HRA methods. These results are presented in Table 2-2.

As part of this process, four contemporary PSF-intensive methods were selected by HRA analysts for comparison. These other methods were HEART (Williams, 1992), CREAM (Hollnagel, 1994), accident sequence evaluation program (ASEP) (Swain, 1987), and THERP (Swain and Guttman, 1983). 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 tabular form 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 1.0 when there is inadequate time available for crew response. In terms of the lower bound, the SPAR-H method

Table 2-2. Action PSF comparison matrix. full 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 available | **.1** | | | | |
| | Time available > 50 x time required | **0.01** | | **0.5** – CPC 18 | **0.01** -Table 7.2 | **0.01** - Table 20.1 |
| Stress | Extreme | **5** | | | **5** -Table 7.3 | **5, 25** - Table 20-16 |
| | High | **2** | **1.3** - EPC 29<br>**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<br>**3** – EPC 15<br>**8** – EPC 6<br>**6** – EPC 9<br>**4** – EPC 12<br>**2.5** – EPC 18<br>**2** – EPC 20<br>**1.6** – EPC 24 | **2** – CPC 25 | **10** -Table 8.3 | **2** - Table 20-16 |

Table 2-2. (continued).

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

Table 2-2. (continued).

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

Table 2-3. HRA methods used in SPAR-H comparisons.

| HRA Method | Date | Authors | Focus - Purpose |
|---|---|---|---|
| Cognitive Reliability and Error Analysis (CREAM) Method | 1998 | E. Hollnagel | Human performance classification based on error modes & consequences (phenotypes) & causes (genotypes). Uses simple Contextual Control Model (CoCoM) of cognition that includes continuous revision and review of goals and intentions. Assesses cognitive function failures & common performance conditions (CPCs) to support failure rate estimations. |
| Human Error Analysis and Reduction Technique (HEART) | 1988 | J. Williams | HRA based on 9 generic tasks with nominal error rates. Analysts identify error producing conditions (EPCs). They function as multipliers; their basis is in the behavioral sciences literature. |
| Technique for Human Error Rate Prediction (THERP) | 1983<br>(NUREG/CR- 1278)<br>[Developed in the 1970s and refined in early 1980s]. | A.D. Swain & 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. |
| Accident Sequence Evaluation Program (ASEP) Human Reliability Analysis Procedure | 1987<br>NUREG/CR-4772 | A.D. Swain | Developed to provide an efficient method for estimation of screening HEPs for pre-accident and post-accident human actions. Based on THERP. |

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 selection of one of three common performance conditions (CPC) (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 upon 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 0.8 (CREAM) 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 1.0. 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 non-control room activities without procedures, the assignment of 1.0 used in ASEP seemed severe. Therefore, the SPAR-H method adopts the THERP assessment for performance in the absence of procedures.

For the ergonomics category, missing or misleading indication uses a multiplier of 50 (SPAR-H method). ASEP and THERP use a larger adjustment, ranging from a factor of 100 or 1,000 (THERP) to complete failure (ASEP). The SPAR-H method assigns a multiplier of 10 for situations involving poor ergonomic, as do HEART and THERP (Table 20.10). CREAM limits the influence of poor ergonomics to a multiplier of 5, and ASEP does not address it.

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

Work processes is used as a PSF in the SPAR-H method, HEART and CREAM. Both CREAM and the SPAR-H method assign a multiplier of 2 in instances where work processes are deemed poor. HEART has 6 different error producing conditions in which poor work processes are included. The highest multiplier available to the analyst is 2.0. CREAM also has 4 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. CREAM (CPC 26) allows for base error probabilities to be reduced by a factor of 0.5 for instances where work processes are deemed good, SPAR-H allows for base error rates to be reduced by a factor 0.8.

Lastly, we note that the SPAR-H PSFs are specified only to single digit precision. Other

methods utilized PSF factors with what may be unrealistic levels of implied precision. For example, some of the HEART multipliers are described via two or three digits (e.g., 1.15 for high stress), which is unwarranted.

### 2.4.2 Discussion of PSF Changes

PSF changes were driven by several considerations. The first consideration was consonance with the other methods. A second consideration was a desire to achieve realistic values; and a third consideration was to reserve as much of the 1994 ASP HRA values as possible, since they had been at least partially validated by application review by inspectors, SPAR model analysts, and HRA practitioners. A final consideration was to examine differences between the two error types in PSF weights. Also at this point, consideration was given to changing the 1994 ASP HRA error type-based error rates. However, no changes were made to these rates.

Another examination was then made for internal and external consistency. The resulting 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.

Following the update to the SPAR-H method, SPAR-H method base failure rates compared favorably with base failure rates associated with the various other 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 possible to easily determine purely a base rate from a composite rate, another HEP or base rate was used. Further discussion of base rate comparison 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 has been presented 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 later 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 upon performance. For example, training is well understood to influence performance both positively (when training emphasizes the correct 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. 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. It is important to note that PSFs have a significant effect on prediction of performance reliability. For example, an objective measure of fitness for duty may be the time (in hours) since last sleep, which has a variable influence on the performance of different individuals. 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.

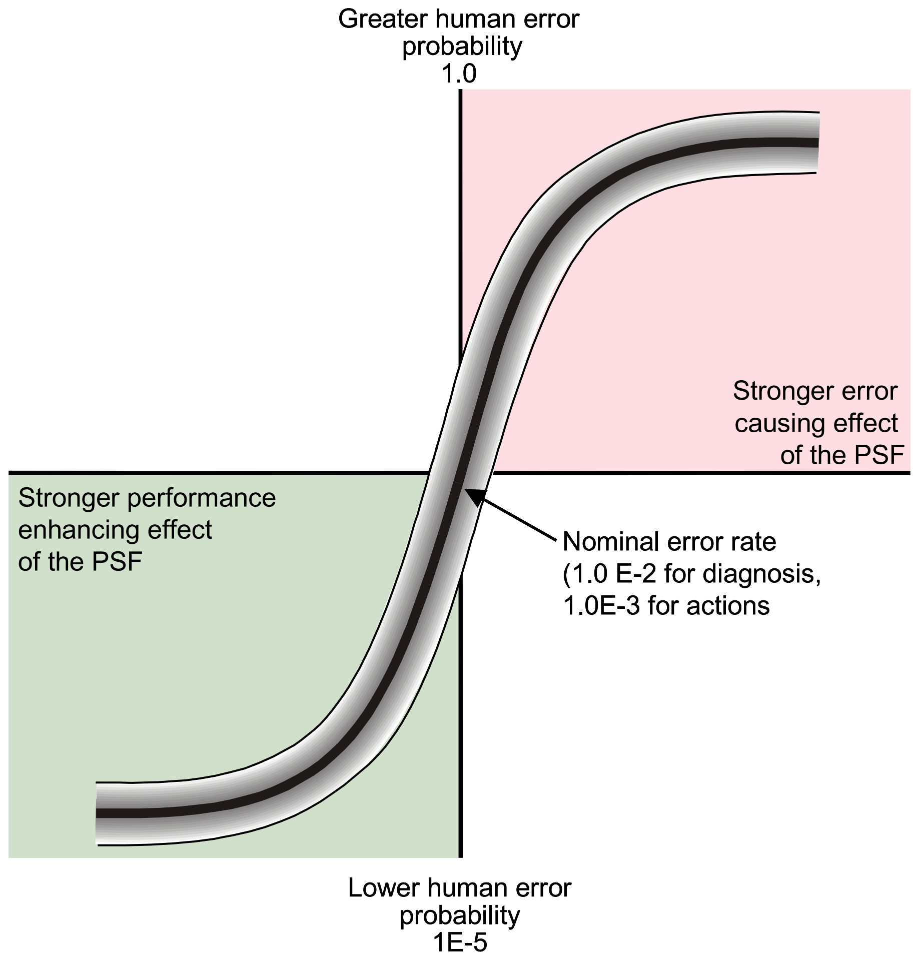


Figure 2-2. Idealized mean HEP as a function of PSF influence.

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 objectively establish the level of a particular PSF. In addition, uncertainty associated with interactions among the PSFs influences the HEP. Factors that contribute 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 2.6.5. Standard HRA also assumes that error can be appropriately modeled with a logarithmic function. Although we demonstrate how 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.

### 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.

#### *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.

#### *2.4.4.2 Diagnosis (Full 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 (< 20 min) – there is less than 20 minutes to diagnose the problem.

Nominal time (~ 30 min) – there is sufficient time (approximately 30 minutes) to diagnose the problem. ***This is the best estimate of the PSF level if you do not have sufficient information to choose among the other alternatives.***

Extra time (> 60 min) – there is a surplus of time (60 minutes or more) to diagnose the problem.

Expansive time (> 24 hrs) – there is extensive time (a day or more) to diagnose the problem and act.

#### *2.4.4.3 Action(Full 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. ***This is the best estimate of the PSF level if you do not have sufficient information to choose among the other alternatives.***

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

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

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

#### *2.4.4.4 Stress*

Stress 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). Environmental factors such as excessive heat, noise, poor ventilation, or radiation can induce stress 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.

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, 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. ***This is the best estimate of the PSF level if you do not have sufficient information to choose among the other alternatives.***

#### 2.4.4.5 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.

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. ***This is the best estimate of the PSF level if you do not have sufficient information to choose among the other alternatives.***

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 (like smells, sounds, 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 circuit of a PWR, pressurizer heater activations, and additional fluctuations in feed flow to the affected steam generator are compelling cues. They indicate a possible steam generator tube rupture (SGTR).

#### 2.4.4.6 Experience and 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 and 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, either in a training or an operational setting). Specific examples where training might be deficient are: inadequate guidance for bypassing engineered safety functions, or for monitoring reactor conditions during reactivity changes.

Low – less than 6 months experience or training. This level of experience and 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. ***This is the best estimate of the PSF level if you do not have sufficient information to choose among the other alternatives.***

High – extensive experience; performers demonstrate mastery. This level of experience/ training provides operators with extensive knowledge and practice in a wide range of potential situations. Good training makes operators well prepared for possible situations.

#### 2.4.4.7 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.

**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 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 support effective performance. ***This is the best estimate of the PSF level if you do not have sufficient information to choose among the other alternatives.***

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.

**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 support effective performance. ***This is the best estimate of the PSF level if you do not have sufficient information to choose among the other alternatives.***

#### 2.4.4.8 Ergonomics

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. Computer software is included in this PSF. Examples of poor ergonomics may be found in panel design layout, annunciator designs, and labeling.

In panel design layout, event investigations 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.

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 nominal parameter values and create a large enough number of false alarms that the operator or crew misperceives a real alarm as a false alarm.

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 or the human engineering aspects.

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

Poor – the design of the plant negatively impacts task performance (e.g., poor labeling, needed instrumentation can't be seen from a work station where control inputs are made, 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; computer interface is adequate and learnable, although not easy to use). ***This is the best estimate of the PSF level if you do not have sufficient information to choose among the other alternatives.***

Good – the design of the plant influences performance in a positive manner. It provides 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).

#### *2.4.4.9 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 that 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.

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 an individual drowsy and non-alert; or being distracted by personal bad news.

Nominal – the individual is able to carry out tasks; no known performance degradation is observed. ***This is the best estimate of the PSF level if you do not have sufficient information to choose among the other alternatives.***

#### *2.4.4.10 Work Processes*

Work processes refers 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 coordination, command, and control. Work processes also include any management, organizational, supervisory factors that affect performance. Examples seen in event investigations are problems due to information not being communicated during shift turnover, as well as inadequate communication between maintenance crews and operators. Measures could include amount of rework, the risk worth of items in the utility corrective action program backlog, enforcement actions, and turnover.

The shift supervisor plays an important role in work processes. Instances where the shift supervisor gets too involved in the details of an event—in contrast to maintaining a position of leadership and overview in the control room—may lead to degradation in command and control.

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 and communicated). ***This is the best estimate of the PSF level if you do not have sufficient information to choose among the other alternatives.***

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).

## 2.5 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 2002, 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 treatment is intended to bring a degree of standardization 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 INEEL in 1999. The center column, the five levels of dependency, is from NUREG/CR-1278 (Swain and Guttman, 1983). The right hand column developed in 2002 represents other descriptions developed for application with the SPAR-H method to aid the analyst in relating tasks, PSFs, and other aspects of context to the appropriate dependency level. A brief discussion follows. Readers should note that discretion should be employed in determining 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.

The authors believe that dependency between tasks arises from the knowledge or lack of knowledge of the performer of the second task with respect to the occurrence and 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 affected by the same PSFs that are shown in Table 2-3 (available time, complexity, stress, work processes, experience and training; procedures, ergonomics, 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

Table 2-4. SPAR-H dependency rating system.

| Crew, Time, Location & Cue Assignments (INEEL 1999) | SPAR Dependency Level (Swain and Guttman 1983) | Additional Dependency Considerations and Basis for Interpretation (INEEL 2002) |
|---|---|---|
| Same crew, close in time, same location, with or without additional cues | Complete | Any of the following: Lack of feedback, misleading feedback or masking of symptoms *virtually ensures* that preceding failure will cause failure on this task as well.<br>Situation mimics an often-experienced sequence, and sequence triggers a well-rehearsed, well-practiced, inappropriate response. A lapse, slip, or mistake is virtually ensured.<br>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 | Any of the following: Lack of feedback, misleading feedback, or masking of symptoms makes it highly likely that preceding failure will cause failure on this task as well.<br>Situations mimic an often-experienced sequence, sequence triggers a well-rehearsed, well-practiced, inappropriate response. A lapse, slip, or mistake is highly likely to result.<br>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 | Any of the following: Lack of feedback, misleading feedback or masking of symptoms makes it highly likely that preceding failure will cause failure on this task as well.<br>Situations mimic an often-experienced sequence, sequence triggers a well-rehearsed, well-practiced, inappropriate response. A lapse, slip, or mistake is highly likely to result.<br>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 | Any of the following: Lack of feedback, misleading feedback, or masking of symptoms makes it moderately likely that preceding failure will cause failure on this task as well.<br>Situations mimic an often-experienced sequence, sequence triggers a well-rehearsed, well-practiced, inappropriate response. A lapse, slip, or mistake is moderately likely to result.<br>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 | Any of the following: Lack of feedback, misleading feedback, or masking of symptoms makes it somewhat likely that preceding failure will cause failure on this task as well.<br>Situation mimic an often-experienced sequence, sequence triggers a well-rehearsed, well-practiced, inappropriate response. A lapse, slip, or mistake is somewhat likely to result.<br>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 | Any of the following: Likely that preceding failure will cause failure on this task as well.<br>Situations mimic an often-experienced sequence, sequence triggers a well-rehearsed, well-practiced, inappropriate response. A lapse, slip, or mistake is moderately likely to result.<br>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 |

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 short, previous actions or recently experienced events create a mindset that guides decision making.

At the first level, if the operator has no knowledge of a prior task, then that task has no effect on a subsequent task. Obviously this is meant from a cognitive perspective. For example, if a pump is damaged, 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 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 there are additional cues available for the performer of the current task that may serve to influence reaction time, failure rates, and recovery.

The authors considered the following variables: crew (same or different), time, location, and cues to construct a deficiency matrix. These four parameters were combined into 10 rule combinations, yielding a dependency rating from low to complete dependence. A eleventh category, zero dependence, exists but does not appear on Part IV of the SPAR-H worksheet. These 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 simplified HRA analysis.

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

SPAR-H does not include calculations for the influence of success upon subsequent task successes or failures. This decision was made for a number of reasons. First, advice available in NUREG/CR-1278, Chapter 10, suggests that if conditional probability information/data is available for the number of "Failures on Task B, given Success on Task A" that this probability be used to represent the influence of positive dependency. It is our experience that these data are, for most situations, not available and collection of these data sometime in the future could serve to make characterizations regarding human performance more complete. At a minimum, the range of effect for dependency in success space is not well established. In practice, there is more knowledge and agreement regarding the potential negative impact of dependency upon performance. For situations where actuarial data are not available and the analyst wishes to assess the "Failure on Task B, given Failure on Task A," we recommend use of the equations determined from NUREG/CR-1278 that are presented on page 3 of the SPAR-H worksheets. This approach to dependency where dependency mechanisms contribute to deleterious effects on subsequent performance is represented in terms of higher than nominal failure rates.

Second, in NUREG/CR-4772 (1987), Swain chose not to include calculation of the influence of positive dependency when considering post-accident response for either screening or the nominal, i.e., detailed case. In part this is due to ASEP representing a simplified analysis method. SPAR-H is also a simplified method and for *most* application modeling positive dependency is not typically, a large concern. Further, in supplemental guidance and in conversations Swain deferred from emphasizing the use of positive dependency calculations, he felt it more appropriate to model accident

response from a more conservative perspective. However, in recent years, PRA has responded to the need to have analysis tools that are more realistic than conservative. Therefore, it may be appropriate for the U.S. NRC to examine this issue in more depth at a later time.

Notice also that the Swain model presented in NUREG/CR-1278, discusses potential differences among direct versus indirect dependency influences. Examples of the former include the activity where an alarm associated with failure on Task A makes the operator more careful in his execution of Task B. Example of the latter includes the role of PSFs such as stress on future performance of tasks where high stress changes the nature of crew interaction such that the crew would defer to the advice of the shift supervisor on all subsequent tasks where before, they would perform required tasks in a more independent manner. For practical purposes, to ease analyst burden and to make SPAR-H more tractable, the SPAR-H approach does not differentiate between direct and indirect dependency influences. Analysts should discuss dependency mechanisms assumed within the body of the HRA analysis.

Additionally, many of the arguments regarding dependency have a strong theoretical basis and the compilation of HEP dependency information would serve to strengthen *all* existing HRA methods. The field of HRA would benefit from a series of focused studies whose aim it was to validate the parameters and determine sensitivities for various degrees of dependency. The same is true for PSF studies. This information could be used to enhance the fidelity of current HRA methods.

### 2.5.1 Approach to Combined HEP Representing Diagnosis and Action within the Same Task

For situations where the HEP contains elements of diagnosis and action, the SPAR-H approach requires the HRA analyst in straight forward fashion to sum the HEP for diagnosis "$Hep_d$" with the HEP for action "$Hep_a$" to yield a combined $HEP_{da}$. This was decided upon rather than to use alternative approaches to formulating dependency such as a multiplicative approach where the "*success* of diagnosis" on Task 1 [i.e., $(1\text{-}HEP_d)$], is multiplied with the failure of the subsequent action ($HEP_a$) to yield a combined $HEP_{da}$. Readers will note that this is familiar in terms of the approach taken to quantify HRA event trees. While this multiplicative approach may be appropriate when constituting HRA event trees, it is not a preferred approach for individual HEP estimates. The reason the current SPAR-H calculation uses a combined HEP approach is predicated on the following observations:

1. For the majority of applications, the $HEP_{da}$ can best be conceived as a single HEP as opposed to a small HRA event tree containing diagnosis and sub-task failures. This type of situation is best exemplified by tasks where the line between diagnosis and action is blurred. For example, if in controlling flow an operator must first decide how much flow is required and then take a control action almost immediately, a combined HEP is appropriate and is used as such in the SPAR models. If, on the other hand the operator must make a distinct diagnosis, such as diagnose a steam generator tube rupture, and then begin a series of actions, diagnosis is best modeled as a separate task with its own HEP followed by an action (or multiple actions) in response to the initial state diagnosis.

2. NUREG/CR-4772 (p. 8-8) guidance for combined diagnosis/action HEP uses an additive approach for combining HEPs that represents experience and review on the part of Sandia analysts. In their view, for post-accident scenarios, both screening and nominal modeling were amenable to this approach when using a simplified HRA method such as ASEP. Because this is a standard practice and because the combined HEP in SPAR-H represents a situation where a combined HEP has been deemed to the analyst to be preferred over separate diagnosis/action HEPs, an additive approach to formatting the combined HEP is appropriate.

3. The combining of diagnosis and action into

a single HEP should factor how the HEP is to be used. Because we expect the HEPs calculated with the worksheet to represent failure events as opposed to unsafe acts for fault tree propagation, the combined HEP approach, i.e., additive, presented in NUREG/CR-4772 is recommended.

If the combined HEP for action and diagnosis relative to a task is to be used in a fault tree, then the HEP should be "broken apart" and the two HEPs, one depicting "diagnosis" and one, "action" should be modeled separately. Populating any HRA event tree (or fault tree) with combined HEPs based upon the multiplicative approach would double count the influence of success because of the success component within the failure path "aB", i.e., the "a" portion and those similarly combined would have already been accounted for in combined HEP calculation. In addition to separating diagnosis and action when constructing the HRA event tree, the HEPs constituting the fault tree must be reviewed for dependency. Although, two HEP basic events may not be dependent, it is very likely that a portion of HEPs within the fault tree framework underlying one of the basic events will have varying degrees of dependence.

## 2.6 Uncertainty Analysis Suggestions For Using SPAR-H

### 2.6.1 Overview

The SPAR-H method produces a simplified 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 non-orthogonal. 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 multiplicative factors for 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 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 as determined through review of the behavioral science literature. These factors are the PSFs. Eight such factors are used in the SPAR-H method.
- For non-initiators 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 Caveats

Some HRA approaches such as THERP and ASEP make use of lognormal error factors that often produce upper bounds for HEPs that are greater than one. Practitioners were aware of this illogical conclusion and accept 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 utilize 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 utilized for several reasons:

- It takes on the form of a beta distribution for probability-type events.
- It uses a non-informative 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 standard deviations 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 E-5 versus the E-6 range. Therefore, 1E-5 is a justifiable lower cut-off range.

Recent versions of the ASME Standard on PRA (ASME RA-STD-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. They provide a theoretical basis for PSFs in SPAR-H and provide error information supporting the uncertainty approach which follows in Section 2.6.6.

Fitts' Law (1953). Research by Fitts and Seeger (1953) is seminal work in the psychological literature examining choice reaction time and is related to the SPAR-H method action-type. Fitts

found that movement time (selection) was equal to the inverse 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 is provided below:

MT= -log(2*D/W)

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.

Hicks' Law. Hicks 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 associated with selecting a choice increase according to the number of binary choices where:

$T = I_c H$

Where $I_c = 150[0\text{-}157]$msec/bit

H is the amount of information required to make the decisions and is measured in bits. This reflects the fact that people don't 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:

$h_i = \text{Log}_2\ 1/p_i$

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.

Stevens Power Law. Steven's Power Law (Stevens, 1951) may have relevance for the SPAR-H method PSF for training and experience. 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 = reaction time (RT) on trial 1, and
b can be approximated by 0.4
N= number of trails

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

T = A + B * SQRT(D/W)
T = time to move to a target
D = distance to target
W = width of target
A ~ -13 msec
B ~ 108 msec

Meyer's Law. Meyer's Law (Meyer, 1989) 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 which may

vary with the input device.) This model suggests that this aspect of human performance can be modeled with a logarithm 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 (Yerkes and Dodson, 1908). Yerkes-Dodson’s Law states that performance is an inverted U shaped function of attention. (See Figure 2-3 below.) In other words, performance is a quadratic function of arousal.

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 more difficult or intellectual (cognitive) tasks (the operators need to

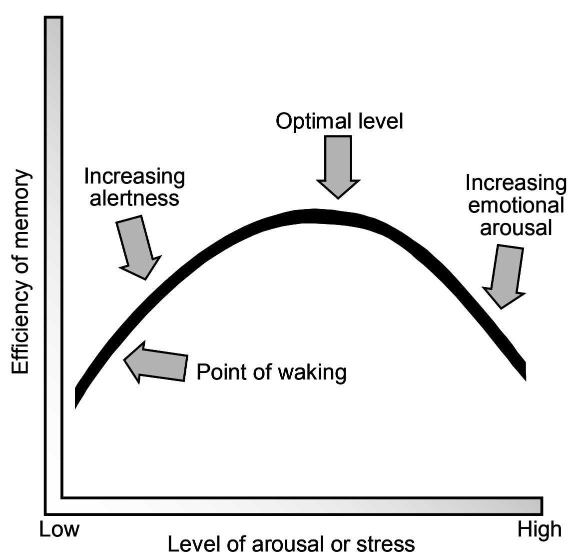


Figure 2-3 Arousal effect on memory

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 PSF for stress and complexity. 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, refer to Section 2.6.6.

A final example of the available models of human performance which do not necessarily require the assumption of a normal distribution of error is the feature model presented in 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, lognormally-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. 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 (i.e., in our example) 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

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

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 upon 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 upon 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 dependent upon the time of day. Work processes may be carried out differently, and supervision may be also be susceptible to these influences.

Even for the lay person, 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 full 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 shifts 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 and Weaver (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.

$L_{ni} = B_n/D_i$

Where $B_n$ is the level of ability of the *nth* person and

$D_i$ is the difficulty of the *ith* 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. Wright and Linacre (1987) 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 $(p_{ni}) * (1\text{-}p_{mi})/(1\text{-}p_{ni}) * (P_{mi})$, 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 $P_{ni}/(1\text{-}P_{ni})$. This can be further transformed into an equal interval linear scale with a logarithmic function with the following form:

$\text{Log}(P_{ni}/(1\text{-}P_{ni})) = B_n - D_i$

or

$P_{ni} = \exp(B_n\text{-}D_i)/(1 + \exp(B_n - D_i))$.

Thus, the item or test (or task difficulty) is only dependent upon the attributes of item *i* and $B_n$ is the measure dependent only on the attributes of person *n*, which can be called his or her ability. Review of these two approaches suggests that:
(1) there may be merit in accounting for complexity from both a subjective, as well as an objective measurement perspective;
(2) difficulty (complexity) may be more than the inverse of ability; and (3) 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 3 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 to reach the desired end state. Inclusion of difficulty as part of the definition is related to early work by Rasch and others in their 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 are logical.

This approach is embraced as part of the Halden 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 (Brookhaven National Laboratory, 2000) and the influence of automation malfunctions on crew performance (O'Hara et al., 2000). A thirty-nine-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 is related 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 were 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 behavioral sciences, but mostly to develop inventories that can be used to assess psycho-social (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) 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, training, fatigue, and general personality and social variables (Proctor and Van Zandt 1993; Hollands and Wickens, 1999). At least one recent study, Hallbert, Sebok, and Morisseau (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.

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 INEEL 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 2-4 presents an influence 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 2-4, 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 upon $PSF_i$. For example, available time has a strong influence on stress; however, stress has a low effect on available time that 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:

- Stress on Complexity—higher levels of stress can make tasks appear more complex than they 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.

### 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" non-informative 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 upon a beta distribution. The beta distribution requires two parameters, $\alpha$ and $\beta$. Atwood (1996) supplied a table of applicable $\alpha$ parameters (as a function of mean HEP). Figure 2-5 shows the numerical value of $\alpha$ 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 $\alpha$ (from the curve) is 0.42. The second parameter, $\beta$, is found via the equation:

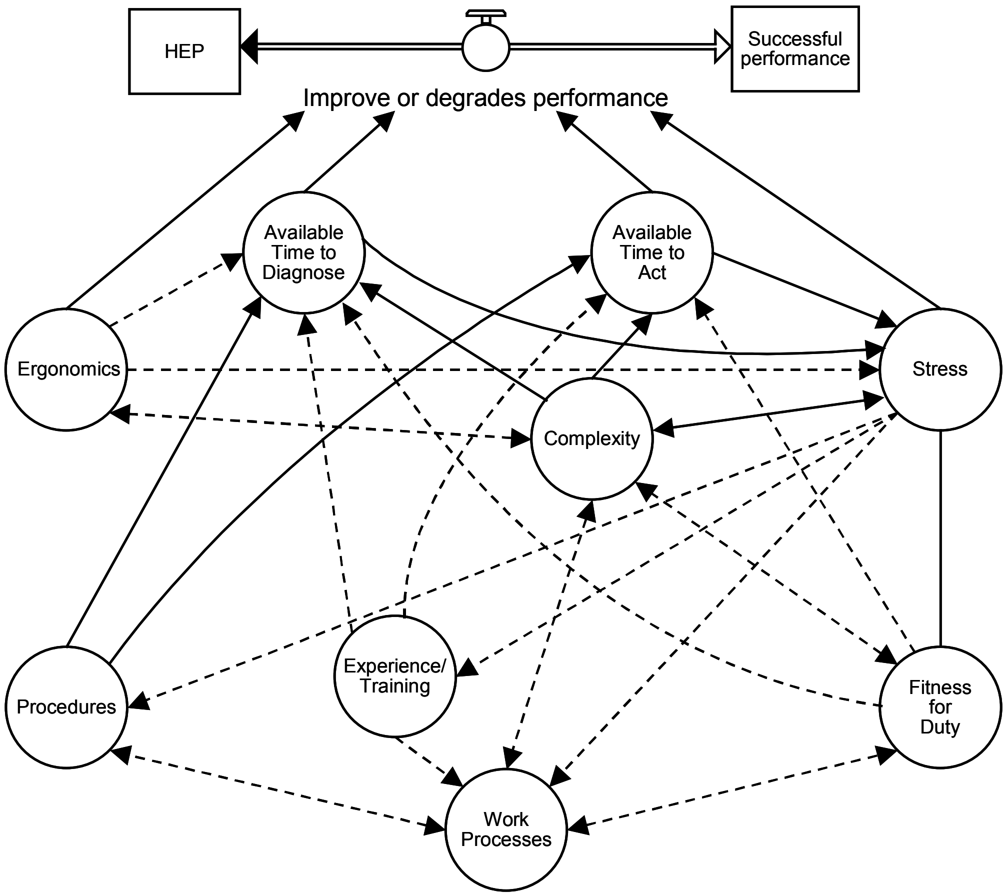


Figure 2-4. Influence diagram showing relationships among PSFs (solid lines denote "high" degree of relationship, dashed lines denote "medium" degree of relationship), see Table G-1.

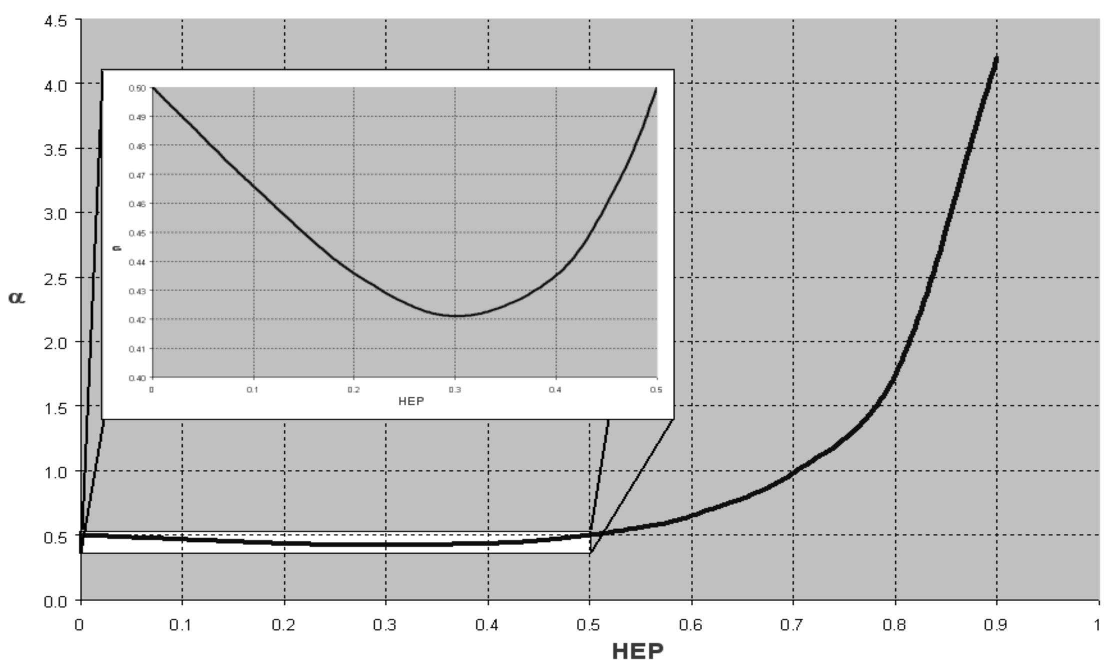


Figure 2-5. "a" as a function of mean HEP.

$\beta = \alpha\,(1 - HEP)/HEP$

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 5th 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 2-6 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 which 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 that is a function of the variable moments and the partial derivative of the model equation.

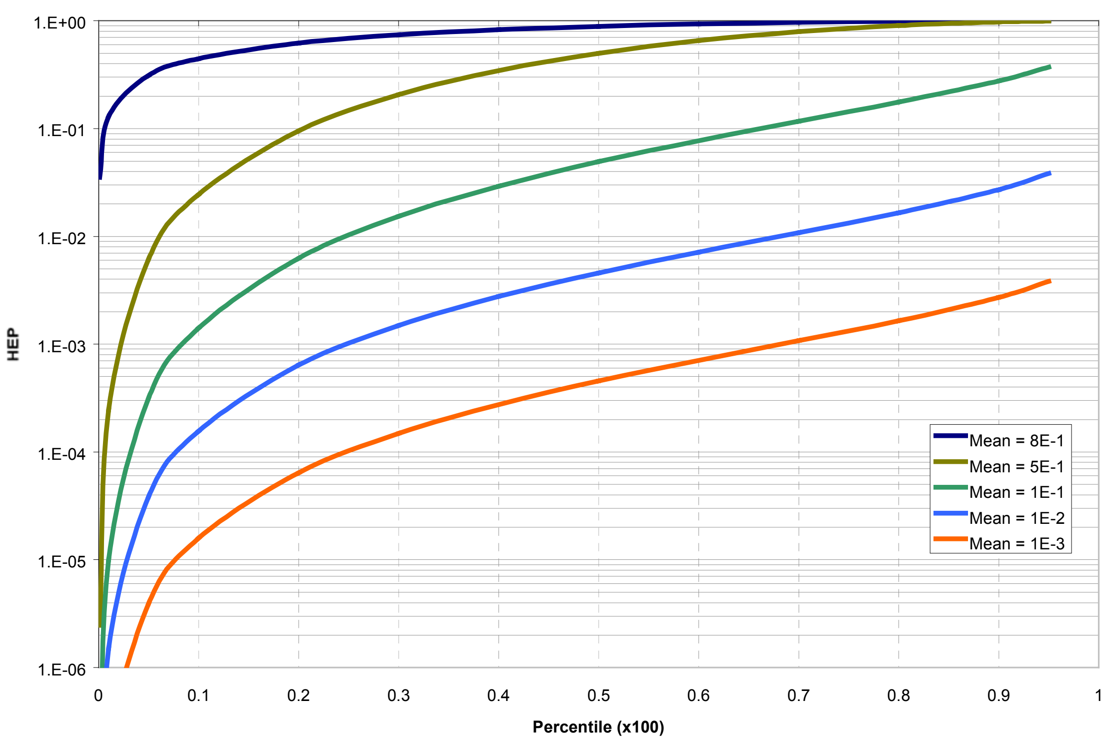


Figure 2-6. CNI distribution for the HEP.

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, only two cases are illustrated, 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*** – $HEP = HEP_1 + HEP_2$

$Mean(HEP) = Mean(HEP_1) + Mean(HEP_2)$

$Var(HEP) = Var(HEP_1) + Var(HEP_2)$

***MULTIPLICATIVE*** – $HEP = HEP_1 \bullet PSF$

$Mean(HEP) = Mean(HEP_1) \bullet Mean(PSF)$

$Var(HEP) = Mean(PSF)^2 \bullet Var(HEP_1) + Mean(HEP_1)^2 \bullet Var(PSF)$

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 utilize 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:

$Mean(X) = \alpha/(\alpha + \beta)$

$Var(X) = \alpha/[(\alpha + \beta + 1)(\alpha + \beta)^2]$

While the approximate method described above is adequate for many cases, analysis tools like 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-STD-2002). In the SPAR-H method, recovery is 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. The current approach allows the analyst to account for as many recovery combinations or opportunities as warranted, and forces this consideration to be explicitly modeled in the logic structures.

# 3. ANALYSIS

## 3.1 Base Rate Comparison Among HRA Methods Including the SPAR-H Method

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 shows the comparison of 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 methods may 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 shows the comparison for mixed rates. That is, the table shows rates for error types whose descriptions partake of both diagnosis and action (or where a distinction can't 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 upon 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.

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.

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.

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

| Method | Error Type Description | Base Rate ($5^{th}$ – $95^{th}$ percentile bounds) |
|---|---|---|
| SPAR | 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 | 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. Shift or restore 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 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 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. Respond 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 & 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 | 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 |

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 2002 SPAR-H method 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.

Validation of PSFs 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 these PSFs, the INEEL 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 are 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, and 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 using the eight SPAR-H PSFs and their 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 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 be

Table 3-4. SPAR (2002) PSFs used in quantifying HEPs.

| PSF | Diagnosis Levels | Action Levels | Range of Influence |
|---|---|---|---|
| Available time | 5 | 5 | .01 to failure |
| Stress | 3 | 3 | 1 to 5 |
| Complexity | 3(4)[a] | 3 | 0.1 to 5 |
| Experience/Training | 3 | 3 | 0.5 to 3 |
| Procedures | 4 | 4 | 0.5 to 50 |
| Ergonomics | 4 | 4 | 0.5 to 50 |
| Fitness for Duty | 3 | 3 | 1 to failure |
| Work Processes | 3 | 3 | 0.8 to 5 |

a. The number in parentheses = the number of levels associated with LP/SD

addressed. For example, the report for the Zion Nuclear Station (NRC Augmented Inspection Team, 1997) shutdown event identified: 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.

## 3.2 Comparison of PSF Weights for Low Power Versus Full Power

LP/SD and full power conditions are generally recognized to be different (more variable in the case of low power, for example). 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 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 whether the changes suggested in the revision would result in:

- Different values when both set 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 full 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 upon field test findings, the assignment of an additional PSF level for procedures was made to both the full power and the LP/SD worksheets. Also, based upon these findings, actions for both worksheets used the same multiples of available time ( >5 x nominal, >50 times nominal) as a result of assigning PSF 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 full power.

Often, tasks may not be fully proceduralized during LP/SD or, in some instances only partially complete procedures are available. Since this may be more prevalent during LP/SD, and workers often can complete their assignments without unduly 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 full power HRA worksheets.

Table 3-5 Assumed differences between LP/SD and Full Power.

| Full Power Mode | LP/SD Conditions | Comments |
|---|---|---|
| More safety systems available. | Fewer safety systems available. | |
| | Refueling operations, mid-loop operations, and draindown are different and performed less frequently. | |
| Transients are consistent in nature and operators more practiced in their response. | Transients are less consistent; operators in control room and others do less 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 for LP/SD. |
| Only 1-2 train(s) of ECCS 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 normally conducted operations. |
| Expected equipment configurations the norm. | Abnormal equipment configurations are often times the norm. | |
| 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 full 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.<br>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 are specified in the work order. None of this will be highly practiced, compared to startup and shutdown procedures on which operators are tested |

| Full Power Mode | LP/SD Conditions | Comments |
|---|---|---|
| | | and trained. |

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 full 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 Full Power and LP/SD HRA worksheets. The influence for the procedures PSF was not changed, and falls within the range of influence implied by other HRA methods.

## 3.3 Approach to LP/SD Comparison

Table 3-5 suggested a number of differences between LP/SD and full 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 A.

To determine if there was a difference in HEP results when analysts used the LP/SD HRA worksheets (i.e., PSF weights versus using the full power worksheets), a comparison of the two types of worksheets was made. This difference is based on a true need for a different HEP and not just an artifact of using the SPAR-H method. This comparison was performed in the following manner:

1) Operations and human factors analysts separately reviewed a LP/SD event sequence and then applied the set of PSF weights (referred to as Weight Set A) used when calculating HEPs for full 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 full power PSF weights resulted in three of the nine HEPs associated with the loss of inventory (LOI) scenario receiving a higher failure rate when compared with HEPs estimated using LP/SD weighting factors. The analysis team indicated that they were more comfortable with the LP/SD weights and that they believed 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 reflected 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 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 estimates cannot be determined without accounting for the contribution of these failures in terms of 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 upon the initiating event sequence.

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

| HEP # 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 |

## 3.4 Additional Field Testing

SPAR-H method 2002 Full 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 INEEL 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, helped them to develop 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 was the SPAR-H method as specifically applied to full power and LP/SD HEP determination, the heuristics described herein may be applicable 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 full 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, the authors 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 INEEL examined other HRA methods and bound 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 [Brookhaven National Laboratory, 1995]) 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 (1999) method error factors. Overall, we observed convergence in error factors. (The authors 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, 1994).

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 2.6.4. The information in 3.5.1 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 being greater than 1.0 or less than 0.0, modification of the distribution is appropriate. (Revision to distributions is considered in Section 2.6.4 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 readers are encouraged to use 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 upon 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 50 times 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 full power scenarios.

Table 3-7. Diagnosis and Action Error Factors for Various HRA Methods.

| Methodology | Diagnosis Error Factors [HEPs] | Action Error Factors [HEPs] | Mixed Uncertainty and Associated HEPs | Comments |
|---|---|---|---|---|
| THERP Screening | 5(0.5),<br>10(0.1, 0.01, 0.001)<br>30(0.0001) | 10(0.05, 0.025) | | Screening Diagnosis - 5 for 10, 10 for 60 and under, 30 for 1 day.<br>Screening actions – 10. |
| THERP | 10 (0.1, 0.01, 0.001)<br>30 (0.0001, 0.00001) | 3(0.001 to 0.01),<br>5(0.003 to 0.5)<br>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.<br>Nominal diagnosis - 10 for 30 and under - 30 for 60 and above<br>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)<br>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)<br>30(0.0001, 0.00001) | 5(0.02, 0.05, 0.25, 0.2, 0.5)<br>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.<br>Error factors from 1.3 to 10<br>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 $5^{th}$ and $95^{th}$ 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 (2002). 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)<br>3(0.001 < x < 0.1)<br>(0.1< x) | | For Action (A), Recovery (R), and Diagnosis (D) events, uncertainty follows a lognormal distribution. |
| SPAR-H | 10 | 3 | | Beta distribution adopted (2002). |
| SPAR-H LP/SD | | | | Beta distribution adopted (2002). |

For diagnosis, time is considered differently. For full 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 2 x nominal; expansive time is defined as greater than 2 x nominal. This reflects: (1) analyst's greater uncertainty in assessing time available during LP/SD, and (2) LP/SD situations where, unlike full 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 (Forester et al., 2000). The new structure for this PSF for diagnosis and actions is listed below.

Diagnosis "Available Time" influence for LP/SD is now structured as:

| | | | |
|---|---|---|---|
| Available Time | Inadequate time | P(failure) = 1.0 | |
| | Barely adequate time (approximately 2/3 x nominal) | 10 | |
| | Nominal time | 1 | |
| | Extra time (≤2 x nominal) | 0.1 | |
| | Expansive time (>2 x nominal) | 0.1 to 0.01* | |

*analyst's choice depending on complexity of diagnosis including multiple factors such as available help, and likelihood of additional cues

Action "Available Time" for both LP/SD and full power is now structured as:

| | | | |
|---|---|---|---|
| Available Time | 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* | |

*analyst's choice depending on complexity, PPE, work environment, and ease of checking and recovery

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 3-8 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 3 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 full power conditions. Use of a nominal estimate, given the context, appears to be more meaningful. In general, additional time may be expected to be beneficial in complicated shutdown situations involving diagnosis. The four events represent basic events that could occur in various LP/SD sequences. In general, increased pressure will result in increased loss of

Table 3-8. 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 rate applied |
| 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.

inventory over situations where the reactor coolant system (RCS) 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 125V 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 (RHR). 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 full 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. The HRA worksheets are similar enough that there may be merit in determining whether the available time domain for full power diagnosis should be reconsidered.

The traditional HRA approach used in the 1999 SPAR-H method worksheets that guided analysts to evaluate available time in terms of minutes in order to assign a multiplier is better suited for some situations than others. For example, the SPAR-H method assigns a multiplier of 10 in instances where only 20 minutes may be available for diagnosis. For some situations, this may be enough time. For

particularly difficult diagnostic situations having one hour available may not be enough (the associated SPAR-H method multiplier for one hour is 0.01, which reduces the base failure rate by a factor of 100). Much of the technical basis for the multipliers associated with available time used in HRA methods comes from diagnosis curves present in older human cognitive reliability (HCR) methods.

The use of multiples of nominal time as a basis for assigning diagnosis multipliers for full power, as is done for LP/SD in the SPAR-H method, may be a better approach. As a starting point, the same PSF definitions used in LP/SD for diagnosis (i.e., inadequate time available; 2/3 nominal; nominal, ≤ 2 x nominal; and > 2 x nominal) could be used to assist in formulating estimates. If this were done, one worksheet could be used for both HRA applications.

Similarly, our approach to complexity ratings for diagnosis tasks executed during LP/SD employed an additional level of complexity that refers to 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 INEEL. The comparison of HEPs for the two worksheets did not detect any difference between the two coding systems for the complexity PSF, but this is a likely function of the LP/SD loss of inventory scenario selected for review. According to operator and HRA analyst evaluation, the diagnosis task reviewed was not highly obvious. If this level of complexity and multiplier were determined to be applicable to full power scenarios, then a single worksheet approach would be possible.

# 4. CONSIDERATIONS WHEN USING THE SPAR-H METHOD FOR FULL POWER AND LP/SD APPLICATION

## 4.1 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 (Forester et al., 2000) 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 HFEs. Human failure events often correspond to basic events in the PRA model. Other HRA approaches include SHARP (Hannaman and Spurgin, 1984), IEEE 1082 (1997), and ASME RA-STD-2002, all of which can provide an overview of the HRA process.

**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 non-deviation 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 (UAs) that are modeled in fault trees. Multiple UAs 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, 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 UAs*. Review critical functions required to mitigate event, identify 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 (EOP)s for vulnerabilities. Sources of information include plant procedures, human-machine interface, and training that lead to operator rules, and available EOPs.

6. *Search for Deviation from the base case scenario*. ATHEANA has advanced a non-traditional 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, develop system and support dependency matrices, and review the potential dependent effects of pre-initiator human actions.

   Analysts also identify operator tendency and error types and match various UAs 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 determination of 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 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 Complexity) on the SPAR-H Human Error Worksheet. The ratings of the last five PSFs (Experience/Training, Procedures, Ergonomics, 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.

## 4.3 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 an 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 that will provide evidence for differences between the base model and the event.

## 4.4 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 (RI). In recent events (such as the degraded condition of the reactor vessel head discovered by Davis Besse) a root cause analysis team report also maybe 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" and the case where insufficient information is available to assign a rating.

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 | More likely to find information about stress in an AIT report than an LER, but in either case it will most likely require some inference on the part of the analyst. More likely to find physical and environmental stressors reported directly. Resident Inspector (RI ) and Plant Management (PM) sources. NRC operator examiners if available. |
| Complexity | RI and NRC operator examiners if available. |
| Experience/Training | AIT report may list for an individual and may comment on shortcomings of training programs. Less likely to find in an LER. Operator examiners if available. |
| Procedures | May be able to request procedures used and evaluate personally. Otherwise LERs sometimes and AITs almost always contain procedures review. |
| Ergonomics | 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 LER. |
| 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 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 find in an AIT report than in an LER. |

Other sources of information that may be of use to the SPAR 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.
- Inspection recommendations.

### 4.4.1 Completing the SPAR-H Human Error Worksheet

The steps below describe the mechanics of completing the SPAR-H Human Error Worksheet. This applies to full power and LP/SD for base models and events.

1. Enter header information at the top of the first page of the SPAR-H Human Error

Worksheet, whether the sequence evaluated is full power or LP/SD:

- 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. This code is present as part of the PRA model.
- 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).

2. Decide if 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 3 and proceed with Step 4.

3. 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 any time a non-nominal rating is made the rater should document the reason for the rating in the block to the right. When there is insufficient information on which to make a rating, use the nominal rating.
- Transfer the multipliers next to the marked checkboxes to the blanks in Section B(2) at the bottom of the first page of the worksheet. Multiply the string of multipliers by 1.0E-2 to calculate the diagnosis failure probability.

4. Enter header information from first page (see Step 1 above) at the top of the second page of the SPAR-H Human Error Worksheet.

5. Complete Part II. Action.

- Rate the eight PSFs for the action portion of the basic event human action by marking one checkbox for each PSF. Note that any time a non-nominal rating is made, the rater should document the reason for the rating in the block to the right. When there is insufficient information on which to make a rating, use the nominal rating.
- Transfer the multipliers next to the marked checkboxes to the blanks in Section B(2) at the bottom of the second page of the worksheet. Multiply the string of multipliers by 1.0E-3 to calculate the action failure probability.

6. Enter abbreviated header information from first page at the top of the third page of the SPAR-H Human Error Worksheet.

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

- Transfer the diagnosis failure probability from page 1 (if diagnosis is involved) and the action failure probability from page 2 to the blanks in Part III on page 3.
- Calculate the task failure probability without formal dependence by adding the diagnosis failure probability to the action failure probability.

8. If the basic event being rated is the first basic event in the sequence, stop here. If the basic event is not the first basic event, proceed to Step 9.

9. Decide if 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 from 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 a reason for not considering HRA dependency quantification, then document the reason(s)

on the line at the top of Part IV and stop here. If not, continue with Step 10.

10. Complete Part IV Dependency

- 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).

- 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.

# 5. DISCUSSION

## 5.1 Differences between Full Power and LP/SD

A number of significant differences between the human actions, errors, and influences important to full 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 full power operations, all classes of human actions and errors (i.e., initiator, pre-accident, 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 full power PRAs. It is typically assumed that human-initiated events while at full 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.

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 (for example, the NRC Generic Letter 88-20 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. The evaluation of reports, event-based data sources, and interviews identified procedures, human engineering, 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 formerly licensed operators.

Procedures are important in modeling human errors in full-power PRAs. However, just as with LP/SD, communications, complexity, and influences such as situation awareness are not always explicitly incorporated as influences on human performance at full power. The event-based data evaluations strongly indicated that contributions from multiple influences are common for human actions and errors during LP/SD and full power events. Also, the available time for event response, frequently an important fact in human performance at full 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 indicated 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, the authors believe that the addition of personnel may serve to 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.

Finally, operators face continuously changing plant conditions and configurations. Frequent changes in the plant situation result in changes in the potential consequences of events and the availability of backup (and, in some cases, front-line) equipment in event responses. Additionally, the changing plant environment during LP/SD increases the importance of communications to safely perform outage activities and to appropriately respond to LP/SD events. Also, equipment is more frequently operated manually during LP/SD operations. Responses to LP/SD events are typically achieved through manual human actions rather than automatic equipment response.

These differences from full power operations help create a situation where 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 uncovery to occur 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 formalized 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 American Society of Mechanical Engineers (ASME) standard for the conduct of PRA was released. The following indicates areas where the SPAR-H method is in compliance and where it is not, and not, why. Just those sections emphasizing HRA are discussed in this report.

ASME Compliance HRA ASME Section 4.5.5.1 Objectives

- Pre-initiator human failure events: maintenance, test, calibration.
- Post-initiator human failure events: human actions performed to prevent or mitigate core damage.
- Need to model (capture) issues of dependency.

The SPAR-H method can be applied to any of the actions cited above. The dependency calculation suggested in the SPAR-H method also meets the concern raised in ASME RA-STD-2002. In general, most high level requirements for HRA, as put forth by the ASME standard, are met by application of the appropriate, standardized search strategies recommended for practice by the SPAR-H method.

The SPAR-H method also meets ASME RA-STD-2002 suggestion (page 48) that assessment of the probabilities of the post initiator HFEs shall be performed using a well-defined and self-consistent process that addresses 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 internally consistent, relatively easy to apply, and simple. Two base rates are proposed, the same eight PSFs are required for evaluation. Defaults are included for situations where no influence by the PSF is expected or where the influence of that PSF is unknown. Assessment of task dependency is straightforward and allows for consideration of elements of context. Quantification follows THERP guidelines.

ASME Section 4.5.5.1 also requires systematic review of relevant procedures. The review of procedure information, coupled with walk downs, interviews and review of event databases, is called out in Section 1 of this report.

For both pre- and post-initiator activities modeling and quantification, the ASME standard requires that the documentation describes the processes used and details of assumptions made. The SPAR-H method calls for this information and, additionally, requires documentation on the HRA worksheets of assumptions made when assigning PSF values that are different than the nominal case.

<u>Supporting requirements for HRA</u>

The SPAR-H method is compatible with the following elements (supporting requirements called forth in the HRA portion of the ASME standard for PRA for nuclear power plant applications)

- Evaluate test and maintenance activities that require realignment of equipment outside its normal operation or standby status.
- Review of calibration activities.
- Identify work practices that could introduce a mechanism that simultaneously impacts the failure probability of multiple systems.
- Establish rules for screening classes of activities. For Capability Category I, II, or III, consider whether plant procedures are structured to include independent checking of restoration of equipment (Cat I), whether equipment is automatically realigned on system demand, or post-maintenance function test is performed that can reveal misalignments (Cat II & III). Also, equipment position is indicated in the control room, status is routinely checked, and realignment can be affected from the control room.
- Define human failure events at a level of detail consistent with that of the system and accident sequence models.
- The SPAR-H method does not call out the above elements directly, however, they are part of the SPAR-H method search strategy. For those performing these searches, the SPAR-H method <u>suggests</u> use of ASME STD or ATHENA strategies to ensure that actions and decisions are properly represented and analyzed.

Pre-initiator HFEs:

Estimate the probabilities of HFEs using a systematic process. Acceptable methods include THERP and ASEP. The SPAR-H method is compatible with and shares a technical basis with THERP and ASEP.

Use detailed assessments for pre-initiator HEPs for dominant system contributors. The SPAR-H method recommends detailed (i.e., complete) HRA for dominant contributors.

The ASME standard requires pre-initiator evaluation of quality of written procedures, administrative controls, or human-machine interface for Capability Category I.

Requirements for Capability Category II or III. The SPAR-H method requires consideration of procedures, administration controls (work practices) and human-machine interfaces (HMI)

(ergonomics) for the quantification of every HEP considered for either actions or diagnosis.

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 component, etc.

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.

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. SPAR-H provides similar guidance.

The ASME standard specifically directs analysts to define a set of HFEs as unavailabilities 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.

The ASME standard specifies the accident sequence specific timing of cues and time window for completion. The SPAR-H method assigns weighting factors based upon available time windows. Timing and appearance of cues is noted in the ergonomics PSF and assumptions for PSF column of the SPAR-H method worksheets.

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. This guidance seems questionable for situations where response is required, but is not captured in procedural guidance, such as might be the case during unusual transients, severe accidents, or complex accidents during LP/SD scenarios.

For screening analysis (CAT I), the ASME standard suggests the 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.

The ASME standard suggests that an HRA approach be used to estimate "HEPs that address failure in cognition as well as failure to execute." The SPAR-H method addresses cognition through diagnosis tasks and action tasks and also allows the analysts to combine rates for tasks having elements of both. The SPAR-H method also allows for PSFs with a cognitive loading, that affect cognition, such as complexity or fitness for duty, to be considered when quantifying actions.

Earlier versions of the ASME standard specified values for screening. That feature has been removed from the standard. Many of the values prescribed were not consistent with approaches used in shutdown HRA, such as that included in NUREG/CR-6144 (Brookhaven National Laboratory, 1995). It also called for relatively high HEPs, on the order of 0.50, for post-initiator 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.

Finally, the ASME standard recommends consideration of the following PSFs:

- Operator training or experience.
- Procedures and administrative controls
- Availability of instrumentation needed to take corrective actions.
- Clarity of cues or indications.

- Human-machine interface.
- Time available and time required.
- Complexity.
- Environment light, heat, radiation, etc.
- Accessibility of equipment requiring manipulation.
- Necessity, adequacy, and availability of special tools, parts, clothing, etc.

Although not mentioned in this list, the ASME standard also calls for review of work practices; at least how they apply to pre-initiator activities. The SPAR-H method covers all of these factors within individual definitions of PSFs plus others, such as fitness for duty and work process factors, in explicit ratings for each HEP.

Task characteristics to consider, that are spelled out in the ASME standard, that fit within the SPAR-H method framework include:

- Number of subtasks.
- Complexity and difficulty of required actions.
- Task performed inside or outside of control room.
- Address both diagnosis and execution for each post-initiator.
- Diagnosis - detecting and 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, ( post initiator 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 be taking 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), Le Bott et al (2000) or Forester (2000). The SPAR-H method doesn't attempt to identify or quantify errors of commission separate from errors of omission. 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 he/she 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 in SPAR 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 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 reflects the high degree of consideration given to the effects of microgravity on task performance. Also, communications 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 upon human performance and allows for quantification based upon 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 Swain and Guttman (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 prior to quantification. In terms of uncertainty, the reasons for use of beta distribution have been summarized earlier in this report.

## 5.4 Method Assessment

In addition to the specific ASME and NASA HRA criteria pertaining to conducting HRA that is reviewed above, the utility of an HRA method, arguably, is also related to its utility to analysts and the risk community in terms of generic acceptance criteria. The evaluation of SPAR-H against generic acceptance criteria is presented in Table 5-1. These criteria include the following: objectivity, consistency, temporal reliability, face and construct validity, documentation and field-testing. Additional criteria include consistency with HRA practice and operating experience, applicability across domains, subject to peer review, compatibility with PRA input requirements, ease of application, and accessible, i.e., easy to obtain. Human factors and HRA analysts reviewed SPAR-H and assigned a consensus rating of either: undetermined, limited, moderate, or high for each of these criteria. Explanations for the rating assignments is contained in the last column of the table.

SPAR-H was rated “high” for the following criteria: producing consistent results, possessing face and construct validity, consistency with HRA practice and operating experience, produces output compatible with PRA, and easy to apply. Predefined PSFs, levels of PSF, established base failure rates and the use of worksheets helps to make the method objective and consistent from analyst to analyst given the same input. SPAR-H is consistent with human behavior models, information processing theory, and accounts for key elements of contemporary HRA. The output obtained from SPAR-H is consistent with analysis of unsafe acts, human failure events and/or basic events supporting PRA analysis. The range of PSFs included in SPAR-H envelopes the PSFs found in operating experience as well as in other HRA methods. SPAR worksheets were designed to produce results that are easily transferred to PRA methods. There is extensive experience in building SPAR models to support this. The use of predefined fields, and range of effect for PSFs including calculation fields and guidance for calculation of dependency make this method easy to apply. Uncertainty calculations are more

involved and SPAR-H guidance is to use the SAPPHIRE workstation software to make this particular task easier.

SPAR-H was rated “moderate” for the following three criteria: field testing and documentation, applicability across domains, and ease with which the method can be obtained. Field testing of the method has been going on for over five years and the use of SPAR-H in model development is on the order of eight years. Documentation for implementing the method has existed but has been limited to NRC staff and a few NRC contractors. Information regarding the method has been formally available to industry through NRC workshops and conferences sponsored jointly with various national or international bodies such as the IEEE, World Association of Nuclear Operators (WANO) or the Organization for Economic Cooperation and Development (OECD). SPAR-H has been applied to ground operations for aerospace, and spent fuel storage activities but experience in applying SPAR-H across additional domains is still needed. With publication of this NUREG/CR, the method should be relatively easy to obtain.

SPAR-H was rated “limited” in terms of peer review and “undetermined” with regard to temporal stability (consistency) of the method. SPAR-H definitions and approach have been refined over the years as a result of comments received from NRC staff. This constitutes a form of peer review. However, peer review will be completed to coincide with publication and receipt of comments from HRA practitioners in NRC and industry over the long term. In the behavioral sciences, a coefficient for temporal stability is determined by having HRA analysts reapply a method such as SPAR-H to the same scenario at a later date and comparing the findings. This analysis has not been conducted by may be performed at a later date.

## 5.5 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 simplified 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 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. 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 is 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, 1992). 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 of work processes influence, 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 thermal-hydraulic computer code with the Analyzer of Dynamic Systems Information, Decision, Action (ADS-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 upon performance because work processes have an indirect and pervasive influence upon 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 objective. 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 25 years since WASH 1400 was issued (Reference 2), appreciation of the importance of human error in nuclear power plants has increased considerably. Starting with a crude diagnosis model based upon 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 processes. In the last ten 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 is 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 where 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 don't 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 in forming current decision-making.

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

Table 5-1 SPAR-H method assessment.

| HRA Method Criterion | SPAR-H Method Rating | Explanation |
|---|---|---|
| The method should be objective and produce consistent results. | High | The use of defined levels of influence, base rates, worksheets serves to produce consistent results, given the same input. |
| It should possess temporal stability. | Undetermined | An existing analysis would have to be re-visited 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 models of human behavior, 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 | Publication in NUREG/CR format and availability on the web and in conference proceedings, information about the method is easily obtained. |

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# Appendix A
# 2002 HRA Worksheets for Full Power
### SPAR HUMAN ERROR WORKSHEET FULL POWER OPERATIONS (PAGE 1 OF 3)

**Plant:__________Initiating Event:________Basic Event :____________**

**Basic Event Context:______________________________________________________________________**

**Basic Event Description:_________________________________________________________________**

Does this task contain a significant amount of diagnosis activity? YES ☐ (start with Part I–Diagnosis (p.1) NO ☐ (skip Part I – Diagnosis (p.1); start with Part II – Action (p.2)) Why?_____________________________________

### PART I. DIAGNOSIS

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

| PSFs | PSF Levels | Multiplier for Diagnosis | If non-nominal PSF levels are selected, please note specific reasons in this column. |
|---|---|---|---|
| Available Time | Inadequate time | P(failure) = 1.0☐ | |
| | Barely adequate time (<20 min) | 10 ☐ | |
| | Nominal time (>20 but <60 min) | 1 ☐ | |
| | Extra time (> 60 min) | 0.1 ☐ | |
| | Expansive time (> 24 hours) | 0.01 ☐ | |
| Stress | Extreme | 5 ☐ | |
| | High | 2 ☐ | |
| | Nominal | 1 ☐ | |
| Complexity | Highly complex | 5 ☐ | |
| | Moderately complex | 2 ☐ | |
| | Nominal | 1 ☐ | |
| | Obvious diagnosis | 0.1 ☐ | |
| Experience/Training | Low | 10 ☐ | |
| | Nominal | 1 ☐ | |
| | High | 0.5 ☐ | |
| Procedures | Not available | 50 ☐ | |
| | Incomplete | 20 ☐ | |
| | Available, but poor | 5 ☐ | |
| | Nominal | 1 ☐ | |
| | Diagnostic/symptom oriented | 0.5 ☐ | |
| Ergonomics | Missing/Misleading | 50 ☐ | |
| | Poor | 10 ☐ | |
| | Nominal | 1 ☐ | |
| | Good | 0.5 ☐ | |
| Fitness for Duty | Unfit | P(failure) = 1.0☐ | |
| | Degraded Fitness | 5 ☐ | |
| | Nominal | 1 ☐ | |
| Work Processes | Poor | 2 ☐ | |
| | Nominal | 1 ☐ | |
| | Good | 0.8 ☐ | |

**B. Calculate the Diagnosis Failure Probability.**

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

Diagnosis: 1.0E-2 x ___ x ___ x ___ x ___ x ___ x ___ x ___ x ___ = ___ **Diagnosis Failure Probability**

## SPAR Human Error Worksheet *Full Power* Operations (Page 2 of 3)

**Plant:__________Initiating Event:_______Basic Event :____________**

**Basic Event Context:____________________________________________________________**

**Basic Event Description:_________________________________________________________**

## Part II. ACTION

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

| PSFs | PSF Levels | Multiplier for Action | If non-nominal PSF levels are selected, please note specific reasons 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 ☐ | |
| Stress | Extreme | 5 ☐ | |
| | High | 2 ☐ | |
| | Nominal | 1 ☐ | |
| Complexity | Highly complex | 5 ☐ | |
| | Moderately complex | 2 ☐ | |
| | Nominal | 1 ☐ | |
| Experience/Training | Low | 3 ☐ | |
| | Nominal | 1 ☐ | |
| | High | 0.5 ☐ | |
| Procedures | Not available | 50 ☐ | |
| | Incomplete | 20 ☐ | |
| | Available, but poor | 5 ☐ | |
| | Nominal | 1 ☐ | |
| Ergonomics | Missing/Misleading | 50 ☐ | |
| | Poor | 10 ☐ | |
| | Nominal | 1 ☐ | |
| | Good | 0.5 ☐ | |
| Fitness for Duty | Unfit | P(failure) = 1.0 ☐ | |
| | Degraded Fitness | 5 ☐ | |
| | Nominal | 1 ☐ | |
| Work Processes | Poor | 5 ☐ | |
| | Nominal | 1 ☐ | |
| | Good | 0.5 ☐ | |

**B. Calculate the Action Failure Probability.**

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

Action: 1.0E-3 x ___ x ___ x ___ x ___ x ___ x ___ x ___ x ___ = ___ **Action Failure Probability**

# SPAR-H Human Error Worksheet *Full Power* Operations (Page 3 of 3)

**Plant:__________Initiating Event:_______Basic Event :____________**

## PART III. CALCULATE THE 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, p.1) and the Action Failure Probability (from Part II, p. 2). In instances where an action is required without a diagnosis and there is no dependency then this step is omitted.

Task Failure Without Formal Dependence ($P_{w/od}$) = ______

---

## 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 ($P_{w/od}$).

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

| Crew (same or different) | Time (close in time or not close in time) | Location (same or different) | Cues (additional or not additional) | Dependency | Number of Human Action Failures Rule ☐ - Not Applicable. Why?_________________ |
|---|---|---|---|---|---|
| Same | Close | Same | * | complete | When considering recovery in a series e.g., 2nd, 3rd, or 4th checker |
| | | Different | * | high | |
| | Not Close | Same | No Additional | high | If this error is the **3rd error in the sequence**, then the dependency is at least **moderate**. |
| | | | Additional | moderate | |
| | | Different | No Additional | moderate | If this error is the **4th error in the sequence**, then the dependency is at least **high.** |
| | | | Additional | low | |
| Different | Close | Same | No Additional | moderate | |
| | Not Close | Different | Additional | low | |

*Cue status not a determining feature for the combination of factors.

Using $P_{w/od}$ = Probability of Task Failure Without Formal Dependence (calculated in Part III, p.3):

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 $P_{w/od}$

Additional criteria for levels of dependence are contained elsewhere in this document.

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

(1 + (          *          ))/          =          **Task Failure Probability With Formal Dependence ($P_{w/od}$)**

# Appendix B
# 2002 HRA Worksheets for LP/SD

## SPAR Human Error Worksheet *LP/SD* Operations (Page 1 of 3)

**Plant:__________Initiating Event:_______Basic Event :____________**

**Basic Event Context:______________________________________________**

**Basic Event Description: __________________________________________**

Does this task contain a significant amount of diagnosis activity? YES ☐ (start with Part I–Diagnosis (p.1) NO ☐ (skip Part I – Diagnosis (p.1); start with Part II – Action (p.2)) Why?________________________

## PART I. DIAGNOSIS

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

| PSFs | PSF Levels | Multiplier for Diagnosis | If non-nominal PSF levels are selected, please note specific reasons in this column. |
|---|---|---|---|
| Available Time | Inadequate time | P(failure) = 1.0 ☐ | |
| | Barely adequate time (≅2/3 x nominal) | 10 ☐ | |
| | Nominal time | 1 ☐ | |
| | Extra time ≤2 x nominal | 0.1 ☐ | |
| | Expansive time > 2 x nominal | 0.1 to 0.01 ☐ | |
| Stress | Extreme | 5 ☐ | |
| | High | 2 ☐ | |
| | Nominal | 1 ☐ | |
| Complexity | Highly complex | 5 ☐ | |
| | Moderately complex | 2 ☐ | |
| | Nominal | 1 ☐ | |
| | Obvious diagnosis | 0.1 ☐ | |
| Experience/Training | Low | 10 ☐ | |
| | Nominal | 1 ☐ | |
| | High | 0.5 ☐ | |
| Procedures | Not available | 50 ☐ | |
| | Incomplete | 20 ☐ | |
| | Available, but poor | 5 ☐ | |
| | Nominal | 1 ☐ | |
| | Diagnostic/symptom oriented | 0.5 ☐ | |
| Ergonomics | Missing/Misleading | 50 ☐ | |
| | Poor | 10 ☐ | |
| | Nominal | 1 ☐ | |
| | Good | 0.5 ☐ | |
| Fitness for Duty | Unfit | P(failure) = 1.0 ☐ | |
| | Degraded Fitness | 5 ☐ | |
| | Nominal | 1 ☐ | |
| Work Processes | Poor | 2 ☐ | |
| | Nominal | 1 ☐ | |
| | Good | 0.8 ☐ | |

**B. Calculate the Diagnosis Failure Probability.**

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

Diagnosis: 1.0E-2x ___ x ___ x ___ x ___ x ___ x ___ x ___ x ___ = ___ **Diagnosis Failure Probability**

**Plant:_________Initiating Event:_______Basic Event :____________**

**Basic Event Context:____________________________________________________________**

**Basic Event Description:________________________________________________________**

## Part II. ACTION

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

| PSFs | PSF Levels | Multiplier for Action | If non-nominal PSF levels are selected, please note specific reasons in this column. |
|---|---|---|---|
| Available Time | Inadequate time | P(failure) = 1.0 ☐ | |
| | Time available is ≈ the time required | 10 ☐ | |
| | Nominal time | 1 ☐ | |
| | Extra time 2-3x nominal | 0.1 ☐ | |
| | Expansive time >3x nominal | 0.01 ☐ | |
| Stress | Extreme | 5 ☐ | |
| | High | 2 ☐ | |
| | Nominal | 1 ☐ | |
| Complexity | Highly complex | 5 ☐ | |
| | Moderately complex | 2 ☐ | |
| | Nominal | 1 ☐ | |
| Experience/Training | Low | 3 ☐ | |
| | Nominal | 1 ☐ | |
| | High | 0.5 ☐ | |
| Procedures | Not available | 50 ☐ | |
| | Incomplete | 20 ☐ | |
| | Available, but poor | 5 ☐ | |
| | Nominal | 1 ☐ | |
| Ergonomics | Missing/Misleading | 50 ☐ | |
| | Poor | 10 ☐ | |
| | Nominal | 1 ☐ | |
| | Good | 0.5 ☐ | |
| Fitness for Duty | Unfit | P(failure) = 1.0 ☐ | |
| | Degraded Fitness | 5 ☐ | |
| | Nominal | 1 ☐ | |
| Work Processes | Poor | 5 ☐ | |
| | Nominal | 1 ☐ | |
| | Good | 0.5 ☐ | |

**B. Calculate the Action Failure Probability.**

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

Action: 1.0E-3 x __ x __ x __ x __ x __ x __ x __ x __ = **__ Action Failure Probability**

**Plant:_________Initiating Event:_______Basic Event :____________**

## PART III. CALCULATE THE 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, p.1) and the Action Failure Probability (from Part II, p.2). In instances where an action is required without a diagnosis and there is no dependency then this step is omitted.

Task Failure Without Formal Dependence ($P_{w/od}$) = ______

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## 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 ($P_{w/od}$).

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

| Crew (same or different) | Time (close in time or not close in time) | Location (same or different) | Cues (additional or not additional) | Dependency | Number of Human Action Failures Rule ☐ - Not Applicable. Why?_________________ |
|---|---|---|---|---|---|
| Same | Close | Same | * | complete | When considering recovery in a series e.g., $2^{nd}$, $3^{rd}$, or $4^{th}$ checker |
| | | Different | * | high | |
| | Not Close | Same | No Additional | high | If this error is the **3rd error in the sequence**, then the dependency is at least **moderate**. |
| | | | Additional | moderate | |
| | | Different | No Additional | moderate | |
| | | | Additional | low | If this error is the **4th error in the sequence**, then the dependency is at least **high.** |
| Different | Close | Same | No Additional | moderate | |
| | Not Close | Different | Additional | low | |

*Cue status not a determining feature for the combination of factors.

Using $P_{w/od}$ = Probability of Task Failure Without Formal Dependence (calculated in Part III, p.3):

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 $P_{w/od}$

Additional criteria for levels of dependence are contained elsewhere in this document.

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

(1 +       ))/      **)** =      **Task Failure Probability With Formal Dependence ($P_{w/od}$)**

# Appendix C
# 2002 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 place din 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.

## SPAR-H Human Error Worksheet Full Power Operations (Page 1 of 3)

**Plant: Calvert Cliffs Initiating Event: SGTR Basic Event : RCS-XHE-DIAG**

**Basic Event Context:**________________________________________

**Basic Event Description: Operator Fails to Diagnose SGTR**

Does this task contain a significant amount of diagnosis activity? YES ☒ (start with Part I–Diagnosis (p.1) NO ☐ (skip Part I, p. 1; start with Part II, p. 2) 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. DIAGNOSIS

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

| PSFs | PSF Levels | Multiplier for Action | If non-nominal PSF levels are selected, please note specific reasons in this column. |
|---|---|---|---|
| Available Time | Inadequate time | P(failure) = 1.0 ☐ | |
| | Barely adequate time (<20 min) | 10 ☐ | |
| | Nominal time | 1 ☒ | |
| | Extra time (>60 min) | 0.1 ☐ | |
| | Expansive time (>24 hrs) | 0.01 ☐ | |
| Stress | Extreme | 5 ☐ | It is assumed that stress will be higher than normal. |
| | High | 2 ☒ | |
| | Nominal | 1 ☐ | |
| Complexity | Highly complex | 5 ☐ | Medium tube rupture is moderately complex, competing systems (feed versus trying to maintain level control). |
| | Moderately complex | 2 ☒ | |
| | Nominal | 1 ☐ | |
| Experience/Training | Low | 3 ☐ | Simulator training emphasizing diagnosis of SGTR is provided. |
| | Nominal | 1 ☐ | |
| | High | 0.5 ☒ | |
| Procedures | Not available | 50 ☐ | The EOPs are symptom-based. |
| | Incomplete | 20 ☐ | |
| | Available, but poor | 5 ☐ | |
| | Nominal | 1 ☐ | |
| | Diagnostic/symptom oriented | 0.5 ☒ | |
| Ergonomics | Missing/Misleading | 50 ☐ | Plant-specific, SGTR diagnosis simplified by having SG level indication and associated gages available for comparison. |
| | Poor | 10 ☐ | |
| | Nominal | 1 ☐ | |
| | Good | 0.5 ☒ | |
| Fitness for Duty | Unfit | P(failure) = 1.0 ☐ | |
| | Degraded Fitness | 5 ☐ | |
| | Nominal | 1 ☒ | |
| Work Processes | Poor | 2 ☐ | Based upon license examining or review, this plant has good work processes. |
| | Nominal | 1 ☐ | |
| | Good | 0.8 ☒ | |

**B. Calculate the Diagnosis Failure Probability**

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

## SPAR-H Human Error Worksheet Full Power Operations (Page 2 of 3)

**Plant: Calvert Cliffs  Initiating Event: SGTR  Basic Event :**

**Basic Event Context:**____________________________________

**Basic Event Description: Operator fails to diagnose SGTR**

## Part II. ACTION

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

| PSFs | PSF Levels | Multiplier for Action | If non-nominal PSF levels are selected, please note specific reasons 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 ☐ | |
| Stress | Extreme | 5 ☐ | |
| | High | 2 ☐ | |
| | Nominal | 1 ☐ | |
| Complexity | Highly complex | 5 ☐ | |
| | Moderately complex | 2 ☐ | |
| | Nominal | 1 ☐ | |
| Experience/Training | Low | 3 ☐ | |
| | Nominal | 1 ☐ | |
| | High | 0.5 ☐ | |
| Procedures | Not available | 50 ☐ | |
| | Incomplete | 20 ☐ | |
| | Available, but poor | 5 ☐ | |
| | Nominal | 1 ☐ | |
| Ergonomics | Missing/Misleading | 50 ☐ | |
| | Poor | 10 ☐ | |
| | Nominal | 1 ☐ | |
| | Good | 0.5 ☐ | |
| Fitness for Duty | Unfit | P(failure) = 1.0 ☐ | |
| | Degraded Fitness | 5 ☐ | |
| | Nominal | 1 ☐ | |
| Work Processes | Poor | 2 ☐ | |
| | Nominal | 1 ☐ | |
| | Good | 0.8 ☐ | |

**B. Calculate the Action Failure Probability.**

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

Action: 1.0E-3 x ___x ___x ___x ___x ___x ___x ___x ___=______ **Action Failure Probability**

## SPAR-H Human Error Worksheet Full Power Operations (Page 3 of 3)

**Plant: Calvert Cliffs  Initiating Event: SGTR   Basic Event : XHE**

## PART III. CALCULATE THE 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, p.1) and the Action Failure Probability (from Part II, p. 2).

Task Failure Without Formal Dependence ($P_{w/od}$) = __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 ($P_{w/od}$).

If there is a reason why failure on previous tasks should not be considered, explain here: **First task in Sequence**

### Dependency Condition Table

| Crew (same or different) | Time (close in time or not close in time | Location (same or different) | Cues (additional or not additional) | Dependency | Number of Human Action Failures Rule<br>☐ - Not Applicable.<br>Why?____________________________ |
|---|---|---|---|---|---|
| Same | Close | Same | * | complete | When considering recovery in a series e.g., 2nd, 3rd, or 4th checker |
| | | Different | * | high | |
| | Not Close | Same | No Additional | high | If this error is the **3rd error in the sequence**, then the dependency is at least **moderate**. |
| | | | Additional | moderate | |
| | | Different | No Additional | moderate | |
| | | | Additional | low | |
| Different | Close | Same | No Additional | moderate | If this error is the **4th error in the sequence**, then the dependency is at least **high.** |
| | Not Close | Different | Additional | low | . |

* Cue status not a determining feature for this combination of factors.

Using $P_{w/od}$ = Probability of Task Failure Without Formal Dependence (calculated in Part III, p. 3):

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 $P_{w/od}$ using the appropriate values:

(1 + (          *          ))/          =          **Task Failure Probability With Formal Dependence ($P_{w/od}$)**

## SPAR-H Human Error Worksheet for Full Power Operations (Page 1 of 3)

**Plant: Calvert Cliffs  Initiating Event: SGTR   Basic Event : HPI-XHE-XM-THRTL**

**Basic Event Context: HEP 2**

**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, p. 1) NO ☒ (skip Part I, p. 1; start with Part II, p. 2) Why? **Task directed by procedure. Involves turning off some pumps or closing down on throttle valve**.

### PART I. DIAGNOSIS

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

| PSFs | PSF Levels | Multiplier for Diagnosis | If non-nominal PSF levels are selected, please note specific reasons in this column |
|---|---|---|---|
| Available Time | Inadequate time | P(failure) = 1.0 ☐ | |
| | Barely adequate time <20 min | 10 ☐ | |
| | Nominal time (>20 but <60 min) | 1 ☐ | |
| | Extra time >60 min | 0.1 ☐ | |
| | Expansive time >24 hrs | 0.01 ☐ | |
| Stress | Extreme | 5 ☐ | |
| | High | 2 ☐ | |
| | Nominal | 1 ☐ | |
| Complexity | Highly complex | 5 ☐ | |
| | Moderately complex | 2 ☐ | |
| | Nominal | 1 ☐ | |
| | Obvious diagnosis | 0.1 ☐ | |
| Experience/Training | Low | 10 ☐ | |
| | Nominal | 1 ☐ | |
| | High | 0.5 ☐ | |
| Procedures | Not available | 50 ☐ | |
| | Incomplete | 20 ☐ | |
| | Available, but poor | 5 ☐ | |
| | Nominal | 1 ☐ | |
| Ergonomics | Missing/Misleading | 50 ☐ | |
| | Poor | 10 ☐ | |
| | Nominal | 1 ☐ | |
| | Good | 0.5 ☐ | |
| Fitness for Duty | Unfit | P(failure) = 1.0 ☐ | |
| | Degraded Fitness | 5 ☐ | |
| | Nominal | 1 ☐ | |
| Work Processes | Poor | 2 ☐ | |
| | Nominal | 1 ☐ | |
| | Good | 0.8 ☐ | |

**B. Calculate the Diagnosis Failure Probability.**

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

Diagnosis: 1.0E-2x_____x_____x_____x_____x_____x_____x_____x_____=_____ **Diagnosis Failure Probability**

## SPAR-H Human Error Worksheet for Full Power Operations (Page 2 of 3)

**Plant: Calvert Cliffs  Initiating Event: SGTR  Sequence Number:____Basic Event : HPI-XHE-XM-THRTL**

**Basic Event Context: 2nd HEP**

**Basic Event Description: Operator fails to throttle HPI to reduce RCS pressure**

### Part II. ACTION

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

| PSFs | PSF Levels | Multiplier for Action | If non-nominal PSF levels are selected, please note specific reasons 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 ≈ the time required | 10 ☐ | |
| | Nominal time | 1 ☒ | |
| | Time available ≥ 5x the time required | 0.1 ☐ | |
| | Time available>50 x time required | 0.01 ☐ | |
| Stress | 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 ☐ | |
| Complexity | Highly complex | 5 ☐ | More than one pump in more than one train. May also have to bypass interlocks. |
| | Moderately complex | 2 ☒ | |
| | Nominal | 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 ☒ | |
| 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 ☒ | |
| Ergonomics | Missing/Misleading | 50 ☐ | Mimics are good for this. Controls are well labeled. The presentation of the two trains is well layed out. |
| | Poor | 10 ☐ | |
| | Nominal | 1 ☐ | |
| | Good | 0.5 ☒ | |
| Fitness for Duty | Unfit | P(failure) = 1.0 ☐ | Event and personnel specific. |
| | Degraded Fitness | 5 ☐ | |
| | Nominal | 1 ☒ | |
| Work Processes | Poor | 5 ☐ | Determined on the basis of analyst evaluation of plant-specific information. |
| | Nominal | 1 ☐ | |
| | Good | 0.5 ☒ | |

**B. Calculate the Action Failure Probability.**

(1) If all PSF ratings are nominal, then the Action Failure Probability = 1.0E-3

(2) Otherwise, Action is 1.0 E-3 x Time x Stress x Complexity x Experience/Training x Procedures x Ergonomics x Fitness for Duty x Work 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** **Action Failure Probability**

## SPAR-H Human Error Worksheet for Full Power Operations (Page 3 of 3)

**Plant: Calvert Cliffs  Initiating Event: SGTR  Basic Event : HPI-XHE-XM-THRTL**

## PART III. CALCULATE THE 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, p.1) and the Action Failure Probability (from Part II, p. 2).

Task Failure Without Formal Dependence ($P_{w/od}$) = __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 ($P_{wd}$).

If there is a reason why failure on previous tasks should not be considered, explain here: **First HEP is failure to diagnose a SCTR. 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

| Crew (same or different) | Time (close in time or not close in time | Location (same or different) | Cues (additional or not additional) | Dependency | Number of Human Action Failures Rule ☐ - Not Applicable. Why?_____________________________ |
|---|---|---|---|---|---|
| Same | Close | Same | * | complete | When considering recovery in a series e.g., 2nd, 3rd, or 4th checker |
| | | Different | * | high | |
| | Not Close | Same | No Additional | high | If this error is the **3rd error in the sequence**, then the dependency is at least **moderate**. |
| | | | Additional | moderate | |
| | | Different | No Additional | moderate | |
| | | | Additional | low | |
| Different | Close | Same | No Additional | moderate | If this error is the **4th error in the sequence**, then the dependency is at least **high.** |
| | Not Close | Different | Additional | low | . |

* Cue status not a determining feature for this combination of factors.

Using $P_{w/od}$ = Probability of Task Failure Without Formal Dependence (calculated in Part III, p. 3):

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 $P_{w/od}$ using the appropriate values:

(1 + (  *  ))/  =  **Task Failure Probability With Formal Dependence ($P_{w/od}$)**

## SPAR-H Human Error Worksheet for Full Power Operations (Page 1 of 3)

**Plant: <u>Calvert Cliffs</u> Initiating Event: <u>SGTR</u> Basic Event : <u>RCS-XHE-XM-SG</u>**

**Basic Event Context: <u>Preceded by failure to throttle HPI</u>**

**Basic Event Description: <u>Failure to initiate RCS depressurization</u>**

Does this task contain a significant amount of diagnosis activity? YES ☐ (start with Part I–Diagnosis (p.1) NO ☒ (skip Part I, p. 1; start with Part II, p. 2) Why? **<u>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.</u>**

### PART I. DIAGNOSIS

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

| PSFs | PSF Levels | Multiplier for Diagnosis | If non-nominal PSF levels are selected, please note specific reasons in this column |
|---|---|---|---|
| Available Time | Inadequate time | P(failure) = 1.0 ☐ | |
| | Barely adequate time <20 min | 10 ☐ | |
| | Nominal time ≈30 min | 1 ☐ | |
| | Extra time >60 min | 0.1 ☐ | |
| | Expansive time >24 hrs | 0.01 ☐ | |
| Stress | Extreme | 5 ☐ | |
| | High | 2 ☐ | |
| | Nominal | 1 ☐ | |
| Complexity | Highly complex | 5 ☐ | |
| | Moderately complex | 2 ☐ | |
| | Nominal | 1 ☐ | |
| | Obvious diagnosis | 0.1 ☐ | |
| Experience/Training | Low | 10 ☐ | |
| | Nominal | 1 ☐ | |
| | High | 0.5 ☐ | |
| Procedures | Not available | 50 ☐ | |
| | Incomplete | 20 ☐ | |
| | Available, but poor | 5 ☐ | |
| | Nominal | 1 ☐ | |
| Ergonomics | Missing/Misleading | 50 ☐ | |
| | Poor | 10 ☐ | |
| | Nominal | 1 ☐ | |
| | Good | 0.5 ☐ | |
| Fitness for Duty | Unfit | P(failure) = 1.0 ☐ | |
| | Degraded Fitness | 5 ☐ | |
| | Nominal | 1 ☐ | |
| Work Processes | Poor | 2 ☐ | |
| | Nominal | 1 ☐ | |
| | Good | 0.8 ☐ | |

**B. Calculate the Diagnosis Failure Probability**

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

Diagnosis: 1.0E-2x_____x_____x_____x_____x_____x_____x_____x_____=_____ **Diagnosis Failure Probability**

## SPAR-H Human Error Worksheet for Full Power Operations (Page 2 of 3)

**Plant: <u>Calvert Cliffs</u> Initiating Event: <u>SGTR</u> Basic Event : <u>RCS-XHE-XM-SG</u>**

**Basic Event Context: <u>Preceded by failure to throttle HPI</u>**

**Basic Event Description: <u>Operator fails to initiate RCS depressurization</u>**

## Part II. ACTION

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

| PSFs | PSF Levels | Multiplier for Action | If non-nominal PSF levels are selected, please note specific reasons in this column |
|---|---|---|---|
| Available Time | Inadequate time | P(failure) = 1.0 ☐ | Any leak that will pop a relief valve is time critical. |
| | Time available ≈ the time required | 10 ☒ | |
| | Nominal time | 1 ☐ | |
| | Time available ≥5x the time required | 0.1 ☐ | |
| | Time available ≥50 x the time required | 0.01 ☐ | |
| Stress | Extreme | 5 ☒ | You've breached one containment barrier and are concerned about a second barrier (relief valves). |
| | High | 2 ☐ | |
| | Nominal | 1 ☐ | |
| Complexity | Highly complex | 5 ☒ | Not a 1 man 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 ☐ | |
| Experience/Training | Low | 3 ☐ | Lots of training on this. |
| | Nominal | 1 ☐ | |
| | High | 0.5 ☒ | |
| Procedures | Not available | 50 ☐ | Pretty good. Sufficient guidelines exist. |
| | Incomplete | 20 ☐ | |
| | Available, but poor | 5 ☐ | |
| | Nominal | 1 ☒ | |
| Ergonomics | Missing/Misleading | 50 ☐ | Task takes place all over control room – requires time sharing between tasks. |
| | Poor | 10 ☐ | |
| | Nominal | 1 ☒ | |
| | Good | 0.5 ☐ | |
| Fitness for Duty | Unfit | P(failure) = 1.0 ☐ | Event and Personnel specific. |
| | Degraded Fitness | 5 ☐ | |
| | Nominal | 1 ☒ | |
| Work Processes | Poor | 5 ☐ | Plant specific, for this facility as determined by review by license examiners. |
| | Nominal | 1 ☐ | |
| | Good | 0.5 ☒ | |

**B. Calculate the Action Failure Probability.**

(1) If all PSF ratings are nominal, then the Action Failure Probability = 1.0E-3

(2) Otherwise, Action is 1.0E-3 x Time x Stress x Complexity x Experience/Training x Procedures x Ergonomics x Fitness for Duty x Work Processes

Action: 1.0E-3x<u>**10**</u>x<u>**5**</u>x<u>**5**</u>x<u>**0.5**</u>x<u>**1**</u>x<u>**1**</u>x<u>**1**</u>x<u>**0.5**</u>=<u>**0.0625**</u> **Action Failure Probability**

**Plant: <u>Calvert Cliffs</u> Initiating Event: <u>SGTR</u> Basic Event : <u>RCS-XHE-XM-SG</u>**

## PART III. CALCULATE THE 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, p.1) and the Action Failure Probability (from Part II, p. 2).
If all PSFs are nominal, then Otherwise;

Task Failure Without Formal Dependence ($P_{w/od}$) = __0.0625_

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## 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 ($P_{w/od}$).

If there is a reason why failure on previous tasks should not be considered, explain here:_____________________

### Dependency Condition Table

| Crew (same or different) | Time (close in time or not close in time | Location (same or different) | Cues (additional or not additional) | Dependency | Number of Human Action Failures Rule<br>☐ - Not Applicable.<br>Why?_________________ |
|---|---|---|---|---|---|
| Same | Close | Same | * | complete | When considering recovery in a series e.g., 2nd, 3rd, or 4th checker<br><br>If this error is the **3rd error in the sequence**, then the dependency is at least **moderate**.<br><br>If this error is the **4th error in the sequence**, then the dependency is at least **high.** |
| | | Different | * | high | |
| | Not Close | Same | No Additional | high | |
| | | | Additional | moderate | |
| | | Different | No Additional | moderate | |
| | | | Additional | low | |
| Different | Close | Same | No Additional | moderate | |
| | Not Close | Different | Additional | low | |

* Cue status no a determining feature for this combination of factors.

Using $P_{w/od}$ = Probability of Task Failure Without Formal Dependence (calculated in Part III, p. 3):

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 $P_{w/od}$ using the appropriate values:

(1 + (6*0.0625))/ 7= 0.196 **Task Failure Probability With Formal Dependence ($P_{w/od}$))**

# Appendix D
# LP/SD Scenario Description and SPAR-H Results for a Hypothetical PWR LOI with RCS Pressurized

## LP/SD Scenario

Loss of Inventory with RCS Pressurized

The scenario evaluated in Appendix D 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 Revision 3i full power operation model for the corresponding plant. The model is organized around a number of plant operating states (POSs) likely to occur during either (1) refueling, (2) plant maintenance with drained reactor coolant system, (3) non-drained maintenance that uses the RHR system for removal of decay heat, or (4) non-drained 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 appendices corresponds to HEPs that would be included as part of the 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 will be presented in the final NUREG version. 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 inventory 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 HPSI, both trains of CVCS, or one train of the low-pressure injection (LPI). These trains include operator failures as well as component unavailability information, and time window (TW) information usually represented at this level of analysis. 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. As with any event analysis, the HEP determined by the SPAR-H screening method only identifies the human error contribution to the basic event frequency.

## SPAR Human Error Worksheet for LP/SD Operations (Page 1 of 3)

**Plant: Plant A      Initiating Event: LOI      Basic Event: RHR-XHE-DIAP2**

**Basic Event Context: Loss of inventory with RCS Pressurized**

**Basic Event Description: Operator Diagnoses Loss of Inventory (1st event)**

Does this task contain a significant amount of diagnosis activity? YES ☒ (start with Part I–Diagnosis (p.1) NO ☐ (skip Part I – Diagnosis (p.1); start with Part II – Action (p.2)) Why?____________________

### PART I. DIAGNOSIS

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

| PSFs | PSF Levels | Multiplier for Diagnosis | If non-nominal PSF levels are selected, please note specific reasons in this column. |
|---|---|---|---|
| Available Time | Inadequate time | P(failure) = 1.0 ☐ | Given that an isolable leak rate is occurring. |
| | Barely adequate time (≅2/3 x nominal) | 10 ☐ | |
| | Nominal time | 1 ☒ | |
| | Extra time (≤ 2 x nominal) | 0.1 ☐ | |
| | Expansive time > 2x nominal | 0.1 to 0.01 ☐ | |
| Stress | Extreme | 5 ☐ | Extreme stress is too dramatic for shutdown activity. |
| | High | 2 ☒ | |
| | Nominal | 1 ☐ | |
| Complexity | Highly complex | 5 ☐ | |
| | Moderately complex | 2 ☐ | |
| | Nominal | 1 ☒ | |
| | Obvious diagnosis | 0.1 ☐ | |
| Experience/Training | Low | 10 ☐ | Extensive training and experience. |
| | Nominal | 1 ☐ | |
| | High | 0.5 ☒ | |
| Procedures | Not available | 50 ☐ | Emergency Operating Procedures (EOPs) are symptom-based. |
| | Incomplete | 20 ☐ | |
| | Available, but poor | 5 ☐ | |
| | Nominal | 1 ☐ | |
| | Diagnostic/symptom oriented | 0.5 ☒ | |
| Ergonomics | Missing/Misleading | 50 ☐ | Less well-designed for LP/SD activities. |
| | Poor | 10 ☒ | |
| | Nominal | 1 ☐ | |
| | Good | 0.5 ☐ | |
| Fitness for Duty | Unfit | P(failure) = 1.0 ☐ | |
| | Degraded Fitness | 5 ☐ | |
| | Nominal | 1 ☒ | |
| Work Processes | Poor | 2 ☐ | |
| | Nominal | 1 ☒ | |
| | Good | 0.8 ☐ | |

**B. Calculate the Diagnosis Failure Probability.**

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

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

## SPAR Human Error Worksheet for LP/SD Operations (Page 2 of 3)

**Plant: Plant A    Initiating Event: LOI    Basic Event: RHR-XHE-DIAP2**

**Basic Event Context: Loss of inventory with RCS Pressurized**

**Basic Event Description: Operator Diagnoses Loss of Inventory (1st event)**

## Part II. ACTION

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

| PSFs | PSF Levels | Multiplier for Action | If non-nominal PSF levels are selected, please note specific reasons in this column |
|---|---|---|---|
| Available Time | Inadequate time | P(failure) = 1.0 ☐ | |
| | Time available is ≈ the time required | 10 ☐ | |
| | Nominal time | 1 ☐ | |
| | Extra time available is 2-3x nominal | 0.1 ☐ | |
| | Expansive time available is >3x nominal | 0.01 ☐ | |
| Stress | Extreme | 5 ☐ | |
| | High | 2 ☐ | |
| | Nominal | 1 ☐ | |
| Complexity | Highly complex | 5 ☐ | |
| | Moderately complex | 2 ☐ | |
| | Nominal | 1 ☐ | |
| Experience/Training | Low | 3 ☐ | |
| | Nominal | 1 ☐ | |
| | High | 0.5 ☐ | |
| Procedures | Not available | 50 ☐ | |
| | Incomplete | 20 ☐ | |
| | Available, but poor | 5 ☐ | |
| | Nominal | 1 ☐ | |
| Ergonomics | Missing/Misleading | 50 ☐ | |
| | Poor | 10 ☐ | |
| | Nominal | 1 ☐ | |
| | Good | 0.5 ☐ | |
| Fitness for Duty | Unfit | P(failure) = 1.0 ☐ | |
| | Degraded Fitness | 5 ☐ | |
| | Nominal | 1 ☐ | |
| Work Processes | Poor | 5 ☐ | |
| | Nominal | 1 ☐ | |
| | Good | 0.5 ☐ | |

**B. Calculate the Action Failure Probability.**

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

Action: 1.0E-3 x ____x ____x ____x ____x ____x ____x ____x ____= _______ **Action Failure Probability**

## SPAR-H Human Error Worksheet for LP/SD Operations (Page 3 of 3)

**Plant: Plant A  Initiating Event: LOI  Basic Event: RHR-XHE-DIAP2**

## PART III. CALCULATE THE 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, p.1) and the Action Failure Probability (from Part II, p.2). In instances where an action is required without a diagnosis and there is no dependency then this step is omitted.

Task Failure Without Formal Dependence ($P_{w/od}$) = __0.05__

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## 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 ($P_{w/od}$).

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

| Crew (same or different) | Time (close in time or not close in time | Location (same or different) | Cues (additional or not additional) | Dependency | Number of Human Action Failures Rule<br>☐ - Not Applicable.<br>Why?___________________________ |
|---|---|---|---|---|---|
| Same | Close | Same | * | complete | When considering recovery in a series e.g., 2nd, 3rd, or 4th checker |
| | | Different | * | high | |
| | Not Close | Same | No Additional | high | If this error is the **3rd error in the sequence**, then the dependency is at least **moderate**. |
| | | | Additional | moderate | |
| | | Different | No Additional | moderate | |
| | | | Additional | low | |
| Different | Close | Same | No Additional | moderate | If this error is the **4th error in the sequence**, then the dependency is at least **high.** |
| | Not Close | Different | Additional | low | |

* Cue status not a determining feature for this combination of factors.

Using $P_{w/od}$ = Probability of Task Failure Without Formal Dependence (calculated in Part III, p.3):

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 $P_{w/od}$

Additional criteria for levels of dependence are contained elsewhere in this document.
Calculate $P_{w/od}$ using the appropriate values:

Task Failure Probability With Formal Dependence ($P_{w/od}$) = (1+(___x___))/x

## SPAR Human Error Worksheet for LP/SD Operations (Page 1 of 3)

**Plant: Plant A     Initiating Event: LOI     Basic Event: RHR-XHE-XX-LOI123**

**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 [X] (start with Part I–Diagnosis (p.1) NO [ ] (skip Part I – Diagnosis (p.1); start with Part II – Action (p.2)) Why?____________________

### PART I. DIAGNOSIS

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

| PSFs | PSF Levels | Multiplier for Diagnosis | If non-nominal PSF levels are selected, please note specific reasons in this column. |
|---|---|---|---|
| Available Time | Inadequate time | P(failure) = 1.0 [ ] | Given that an isolable leak rate is occurring. |
| | Barely adequate time (≅2/3 x nominal) | 10 [ ] | |
| | Nominal time | 1 [X] | |
| | Extra time (< 2 x nominal) | 0.1 [ ] | |
| | Expansive time > 2x nominal | 0.1 to 0.01 [ ] | |
| Stress | Extreme | 5 [ ] | Extreme stress is too dramatic for shutdown activity. |
| | High | 2 [X] | |
| | Nominal | 1 [ ] | |
| Complexity | Highly complex | 5 [ ] | |
| | Moderately complex | 2 [ ] | |
| | Nominal | 1 [X] | |
| | Obvious diagnosis | 0.1 [ ] | |
| Experience/Training | Low | 10 [ ] | Extensive training and experience. |
| | Nominal | 1 [ ] | |
| | High | 0.5 [X] | |
| Procedures | Not available | 50 [ ] | EOPs are system-based. |
| | Incomplete | 20 [ ] | |
| | Available, but poor | 5 [ ] | |
| | Nominal | 1 [ ] | |
| | Diagnostic/symptom oriented | 0.5 [X] | |
| Ergonomics | Missing/Misleading | 50 [ ] | Less well-designed for LP/SD activities. |
| | Poor | 10 [X] | |
| | Nominal | 1 [ ] | |
| | Good | 0.5 [ ] | |
| Fitness for Duty | Unfit | P(failure) = 1.0 [ ] | |
| | Degraded Fitness | 5 [ ] | |
| | Nominal | 1 [X] | |
| Work Processes | Poor | 2 [ ] | |
| | Nominal | 1 [X] | |
| | Good | 0.8 [ ] | |

**B. Calculate the Diagnosis Failure Probability.**

(1) If all PSF ratings are nominal, then the Diagnosis Failure Probability = 1.0E-2
(2) Otherwise, Diagnosis is: 1.0E-2 x Time x Stress x Complexity x Experience/Training x Procedures x Ergonomics x Fitness for Duty x Processes = **Diagnosis Failure Probability**
Diagnosis: 1.0E-2 x 1 x 2 x 1 x 0.5 x 0.5 x 10 x 1 x 1 = **0.05** **Diagnosis Failure Probability**

# SPAR Human Error Worksheet for LP/SD Operations (Page 2 of 3)

**Plant: Plant A    Initiating Event: LOI    Basic Event: RHR-XHE-XX-LOI123**

**Basic Event Context: Loss of inventory with RCS Pressurized**

**Basic Event Description: Failure to Recover RHR**

## Part II. ACTION

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

| PSFs | PSF Levels | Multiplier for Action | If non-nominal PSF levels are selected, please note specific reasons 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. |
| | Barely adequate time (≅2/3 x nominal) | 10 ☐ | |
| | Nominal time | 1 ☒ | |
| | Extra time 2-3 x nominal | 0.5 ☐ | |
| | Expansive Time > 3 x nominal | 0.1 to 0.01 ☐ | |
| Stress | Extreme | 5 ☐ | |
| | High | 2 ☐ | |
| | Nominal | 1 ☒ | |
| Complexity | Highly complex | 5 ☐ | |
| | Moderately complex | 2 ☐ | |
| | Nominal | 1 ☒ | |
| Experience/Training | Low | 3 ☐ | Crew is well trained on residual heat removal (RHR) for full power context. |
| | Nominal | 1 ☐ | |
| | High | 0.5 ☒ | |
| Procedures | Not available | 50 ☐ | Not as well developed for shutdown activities. |
| | Incomplete | 20 ☐ | |
| | Available, but poor | 5 ☒ | |
| | Nominal | 1 ☐ | |
| Ergonomics | Missing/Misleading | 50 ☐ | |
| | Poor | 10 ☐ | |
| | Nominal | 1 ☐ | |
| | Good | 0.5 ☒ | |
| Fitness for Duty | Unfit | P(failure) = 1.0 ☐ | |
| | Degraded Fitness | 5 ☐ | |
| | Nominal | 1 ☒ | |
| Work Processes | Poor | 5 ☐ | |
| | Nominal | 1 ☒ | |
| | Good | 0.5 ☐ | |

**B. Calculate the Action Failure Probability.**

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

Action: 1.0E-3 x 1 x 1 x 1 x 0.5 x 5 x 0.5 x 1 x 1 = **0. 00125 Action Failure Probability**

## SPAR-H Human Error Worksheet for *LP/SD* Operations (Page 3 of 3)

**Plant: Plant A     Initiating Event: LOI___Basic Event: RHR-XHE-XX-LOI123**

## PART III. CALCULATE THE 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, p.1) and the Action Failure Probability (from Part II, p.2). In instances where an action is required without a diagnosis and there is no dependency then this step is omitted.

Task Failure Without Formal Dependence ($P_{w/od}$) = __0.05125____

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## 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 ($P_{w/od}$).

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: **pathway is reached from success on previous tasks.**

### Dependency Condition Table

| Crew (same or different) | Time (close in time or not close in time | Location (same or different) | Cues (additional or not additional) | Dependency | Number of Human Action Failures Rule ☐ - Not Applicable. Why?_________________ |
|---|---|---|---|---|---|
| Same | Close | Same | * | complete | When considering recovery in a series e.g., 2nd, 3rd, or 4th checker |
| | | Different | * | high | |
| | Not Close | Same | No Additional | high | If this error is the **3rd error in the sequence**, then the dependency is at least **moderate**. |
| | | | Additional | moderate | |
| | | Different | No Additional | moderate | |
| | | | Additional | low | If this error is the **4th error in the sequence**, then the dependency is at least **high.** |
| Different | Close | Same | No Additional | moderate | |
| | Not Close | Different | Additional | low | . |

* Cue status not a determining feature for this combination of factors.

Using $P_{w/od}$ = Probability of Task Failure Without Formal Dependence (calculated in Part III, p.3):

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 $P_{w/od}$

Additional criteria for levels of dependence are contained elsewhere in this document.
Calculate $P_{w/od}$ using the appropriate values:

(1 + (__ * __))/__ = ____) **Task Failure Probability With Formal Dependence**

## SPAR Human Error Worksheet for LP/SD Operations (Page 1 of 3)

**Plant:** **Plant A** **Initiating Event:** **LOI** **Basic Event:** **HPI-XHE-XM-FB**

**Basic Event Context:** **Loss of inventory with RCS Pressurized, Failure to start pump & align system**

**Basic Event Description:** **Failure To Force Feed**

Does this task contain a significant amount of diagnosis activity? YES ☒ (start with Part I–Diagnosis (p.1) NO ☐ (skip Part I – Diagnosis (p.1); start with Part II – Action (p.2)) Why?__________

## PART I. DIAGNOSIS

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

| PSFs | PSF Levels | Multiplier for Diagnosis | If non-nominal PSF levels are selected, please note specific reasons in this column. |
|---|---|---|---|
| Available Time | Inadequate time | P(failure) = 1.0 ☐ | Given that an isolable leak rate is occurring. |
| | Barely adequate time (≅2/3 x nominal) | 10 ☐ | |
| | Nominal time | 1 ☒ | |
| | Extra time (≤ 2 x nominal) | 0.1 ☐ | |
| | Expansive time > 2x nominal | 0.1 to 0.01 ☐ | |
| Stress | Extreme | 5 ☐ | Stress is present, however, extreme stress is too dramatic for shutdown activity. |
| | High | 2 ☒ | |
| | Nominal | 1 ☐ | |
| Complexity | Highly complex | 5 ☐ | |
| | Moderately complex | 2 ☐ | |
| | Nominal | 1 ☒ | |
| | Obvious diagnosis | 0.1 ☐ | |
| Experience/Training | Low | 10 ☐ | Extensive training and experience for this type of task. |
| | Nominal | 1 ☐ | |
| | High | 0.5 ☒ | |
| Procedures | Not available | 50 ☐ | EOPs are symptom-based. |
| | Incomplete | 20 ☐ | |
| | Available, but poor | 5 ☐ | |
| | Nominal | 1 ☐ | |
| | Diagnostic/symptom oriented | 0.5 ☒ | |
| Ergonomics | Missing/Misleading | 50 ☐ | Less well-designed for LP/SD activities. |
| | Poor | 10 ☒ | |
| | Nominal | 1 ☐ | |
| | Good | 0.5 ☐ | |
| Fitness for Duty | Unfit | P(failure) = 1.0 ☐ | |
| | Degraded Fitness | 5 ☐ | |
| | Nominal | 1 ☒ | |
| Work Processes | Poor | 2 ☐ | |
| | Nominal | 1 ☒ | |
| | Good | 0.8 ☐ | |

**B. Calculate the Diagnosis Failure Probability.**

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

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

## SPAR Human Error Worksheet for *LP/SD* Operations (Page 2 of 3)

**Plant: Plant A  Initiating Event: LOI  Basic Event: HPI-XHE-XM-FB**

**Basic Event Context: Loss of inventory with RCS Pressurized, Failure to start pump & align system**
**Basic Event Description**: **Failure To Force Feed**

## Part II. ACTION

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

| PSFs | PSF Levels | Multiplier for Action | If non-nominal PSF levels are selected, please note specific reasons in this column. |
|---|---|---|---|
| Available Time | Inadequate time | P(failure) = 1.0 ☐ | |
| | Barely adequate time (≅2/3 x nominal) | 10 ☐ | |
| | Nominal time | 1 ☐ | |
| | Extra time 2-3 x nominal | 0.5 ☐ | |
| | Expansive Time >3 x nominal | 0.1 to 0.01 ☒ | |
| Stress | Extreme | 5 ☐ | |
| | High | 2 ☐ | |
| | Nominal | 1 ☒ | |
| Complexity | Highly complex | 5 ☐ | . |
| | Moderately complex | 2 ☒ | |
| | Nominal | 1 ☐ | |
| Experience/Training | Low | 3 ☐ | |
| | Nominal | 1 ☐ | |
| | High | 0.5 ☒ | |
| Procedures | Not available | 50 ☐ | |
| | Incomplete | 20 ☐ | |
| | Available, but poor | 5 ☐ | |
| | Nominal | 1 ☒ | |
| Ergonomics | Missing/Misleading | 50 ☐ | |
| | Poor | 10 ☐ | |
| | Nominal | 1 ☒ | |
| | Good | 0.5 ☐ | |
| Fitness for Duty | Unfit | P(failure) = 1.0 ☐ | |
| | Degraded Fitness | 5 ☐ | |
| | Nominal | 1 ☒ | |
| Work Processes | Poor | 5 ☐ | |
| | Nominal | 1 ☒ | |
| | Good | 0.5 ☐ | |

**B. Calculate the Action Failure Probability.**

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

Action: 1.0E-3 x _.1_ x _1_ x _2_ x _0.5_ x _1_ x _1_ x _1_ x _1_ = **_0.001_ Action Failure Probability**

## SPAR-H Human Error Worksheet for *LP/SD* Operations (Page 3 of 3)

**Plant: Plant A    Initiating Event: LOI    Basic Event: HPI-XHE-XM-FB**

## PART III. CALCULATE THE 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, p.1) and the Action Failure Probability (from Part II, p.2). In instances where an action is required without a diagnosis and there is no dependency then this step is omitted.

Task Failure Without Formal Dependence ($P_{w/od}$) = ___0.051___

## 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 ($P_{w/od}$).

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

| Crew (same or different) | Time (close in time or not close in time) | Location (same or different) | Cues (additional or not additional) | Dependency | Number of Human Action Failures Rule<br>☐ - Not Applicable.<br>Why?_________________ |
|---|---|---|---|---|---|
| Same | Close | Same | | complete | When considering recovery in a series e.g., 2nd, 3rd, or 4th checker<br>If this error is the **3rd error in the sequence**, then the dependency is at least **moderate**.<br>If this error is the **4th error in the sequence**, then the dependency is at least **high.** |
| | | Different | * | high | |
| | Not Close | Same | No Additional | high | |
| | | | Additional | moderate | |
| | | Different | No Additional | moderate | |
| | | | Additional | low | |
| Different | Close | Same | No Additional | moderate | |
| | Not Close | Different | Additional | low | |

* Cue status not a determining feature in this combination of factors.

Using $P_{w/od}$ = Probability of Task Failure Without Formal Dependence (calculated in Part III, p.3):

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 $P_{w/od}$

Additional criteria for levels of dependence are contained elsewhere in this document.

Calculate $P_{w/od}$ using the appropriate values:
For complete dependency the Task Failure Probability With Formal Dependence ($P_{w/od}$) = **(1+(1X0.051)/2))=0.5255**

# Appendix E
# Spent Fuel Storage Description and SPAR-H Results for Dry Cask

**Dry Cask Spent Reactor Fuel Storage Examples**

The following two 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 worksheets 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 worksheets 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.

# SPAR-H Human Error Worksheet for LP/SD Operations (Page 1 of 3)

**Plant: Plant X  Initiating Event:______Basic Event : XHE**

**Basic Event Context: Load fuel into the canister**

**Basic Event Description: Failure to properly load fuel assemblies**

Does this task contain a significant amount of diagnosis activity? YES ☒ (start with Part I–Diagnosis (p.1) NO ☐ (skip Part I, p. 1; start with Part II, p. 2) Why? **Multiple assemblies/serial number/specific placement locations/verifications.**

## PART I. DIAGNOSIS

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

| PSFs | PSF Levels | Multiplier for Diagnosis | If non-nominal PSF levels are selected, please note specific reasons in this column |
|---|---|---|---|
| Available Time | Inadequate time | P(failure) = 1.0 ☐ | |
| | Barely adequate time <20 min | 10 ☐ | |
| | Nominal time ≈30 min | 1 ☒ | |
| | Extra time (≤ 2 x nominal) | 0.1 ☐ | |
| | Expansive time (> 2 x nominal) | 0.1 to 0.01 ☐ | |
| Stress | Extreme | 5 ☐ | |
| | High | 2 ☐ | |
| | Nominal | 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 ☐ | |
| Experience/Training | Low | 10 ☐ | |
| | Nominal | 1 ☒ | |
| | High | 0.5 ☐ | |
| Procedures | Not available | 50 ☐ | |
| | Available, but poor | 5 ☐ | |
| | Nominal | 1 ☒ | |
| | Diagnostic/symptom oriented | 0.5 ☐ | |
| Ergonomics | Missing/Misleading | 50 ☐ | Performed by remote control under water using video camera view. (Assembly selection, placement, and verification.) |
| | Poor | 10 ☒ | |
| | Nominal | 1 ☐ | |
| | Good | 0.5 ☐ | |
| Fitness for Duty | Unfit | P(failure) = 1.0 ☐ | |
| | Degraded Fitness | 5 ☐ | |
| | Nominal | 1 ☒ | |
| Work Processes | Poor | 2 ☐ | |
| | Nominal | 1 ☒ | |
| | Good | 0.8 ☐ | |

**B. Calculate the Diagnosis Failure Probability**

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

Diagnosis: 1.0E-2x__1__x__1__x__2__x__1__x__1__x__10__x__1__x__1__=__0.2__ **Diagnosis Failure Probability**

## SPAR-H Human Error Worksheet for LP/SD Operations (Page 2 of 3)

**Plant: Plant X      Initiating Event:______Basic Event : XHE**

**Basic Event Context: Load fuel into the canister**

**Basic Event Description: Failure to properly load fuel assemblies**

## Part II. ACTION

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

| PSFs | PSF Levels | Multiplier for Action | | If non-nominal PSF levels are selected, please note specific reasons in this column. |
|---|---|---|---|---|
| Available Time | Inadequate time | P(failure) = 1.0 | ☐ | |
| | Time available ≈ time required | 10 | ☐ | |
| | Nominal time | 1 | ☒ | |
| | Extra time 2-3 x nominal | 0.5 | ☐ | |
| | Expansive Time > 3 x nominal | 0.1 to 0.01 | ☐ | |
| Stress | Extreme | 5 | ☐ | |
| | High | 2 | ☐ | |
| | Nominal | 1 | ☒ | |
| Complexity | Highly complex | 5 | ☐ | Multiple assemblies with specific placements in canister. |
| | Moderately complex | 2 | ☒ | |
| | Nominal | 1 | ☐ | |
| Experience/Training | Low | 3 | ☐ | Training is available for this task. |
| | Nominal | 1 | ☒ | |
| | High | 0.5 | ☐ | |
| Procedures | Not available | 50 | ☐ | |
| | Available, but poor | 5 | ☐ | |
| | Nominal | 1 | ☒ | |
| Ergonomics | Missing/Misleading | 50 | ☐ | Performed by remote control under water using video camera view. Assembly selection, placement, and verification viewing serial number stamps with underwater camera. |
| | Poor | 10 | ☒ | |
| | Nominal | 1 | ☐ | |
| | Good | 0.5 | ☐ | |
| Fitness for Duty | Unfit | P(failure) = 1.0 | ☐ | |
| | Degraded Fitness | 5 | ☐ | |
| | Nominal | 1 | ☒ | |
| Work Processes | Poor | 5 | ☐ | |
| | Nominal | 1 | ☒ | |
| | Good | 0.5 | ☐ | |

**B. Calculate the Action Failure Probability.**

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

Action: 1.0E-3x_1_x_1_x_2_x_1_x_1_x_10_x_1_x_1_=_0.02__**Action Failure Probability**

## SPAR-H Human Error Worksheet for LP/SD Operations (Page 3 of 3)

**Plant: <u>Plant X</u>   Initiating Event:______Basic Event : <u>XHE</u>**

## PART III. CALCULATE THE 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, p.1) and the Action Failure Probability (from Part II, p. 2).

Task Failure Without Formal Dependence ($P_{w/od}$)= 0.22   $P_{(w/od)}$= 1.1E-2

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## 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 ($P_{w/od}$).

If there is a reason why failure on previous tasks should not be considered, explain here:_____________________

### Dependency Condition Table

| Crew (same or different) | Time (close in time or not close in time | Location (same or different) | Cues (additional or not additional) | Dependency | Number of Human Action Failures Rule<br>☐ - Not Applicable.<br>Why?___________________________ |
|---|---|---|---|---|---|
| Same | Close | Same | * | complete | When considering recovery in a series e.g., 2nd, 3rd, or 4th checker |
| | | Different | * | high | |
| | Not Close | Same | No Additional | high | If this error is the **3rd error in the sequence**, then the dependency is at least **moderate**. |
| | | | Additional | moderate | |
| | | Different | No Additional | moderate | |
| | | | Additional | low | If this error is the **4th error in the sequence**, then the dependency is at least **high.** |
| Different | Close | Same | No Additional | moderate | |
| | Not Close | Different | Additional | low | . |

* Cue status not a determining feature for this combination of factors.

Using $P_{w/od}$ = Probability of Task Failure Without Formal Dependence (calculated in Part III, p. 3):

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 $P_{w/od}$ using the appropriate values:

(1 + (  *  ))/   = **1.0 Task Failure Probability With Formal Dependence ($P_{w/od}$)**

## SPAR-H Human Error Worksheet for LP/SD Operations (Page 1 of 3)

**Plant: Plant X     Initiating Event:______Basic Event : XHE**

**Basic Event Context: Cask closure**

**Basic Event Description: Operators fail to properly perform vacuum drying system connections and setup.**

Does this task contain a significant amount of diagnosis activity? YES ☒ (start with Part I–Diagnosis (p.1) NO ☐ (skip Part I, p. 1; start with Part II, p. 2) Why? **Multiple steps, multiple components, connections, manipulations.**

### PART I. DIAGNOSIS

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

| PSFs | PSF Levels | Multiplier for Diagnosis | If non-nominal PSF levels are selected, please note specific reasons in this column. |
|---|---|---|---|
| Available Time | Inadequate time | P(failure) = 1.0 ☐ | |
| | Barely adequate time <20 min | 10 ☐ | |
| | Nominal time ≈30 min | 1 ☒ | |
| | Extra time (≤ 2 x nominal) | 0.1 ☐ | |
| | Expansive time (> 2 x nominal) | 0.1 to 0.01 ☐ | |
| Stress | Extreme | 5 ☐ | |
| | High | 2 ☐ | |
| | Nominal | 1 ☒ | |
| Complexity | Highly complex | 5 ☐ | Multiple steps, multiple components, connections, and manipulations. |
| | Moderately complex | 2 ☒ | |
| | Nominal | 1 ☐ | |
| | Obvious diagnosis | 0.1 ☐ | |
| Experience/Training | Low | 10 ☐ | |
| | Nominal | 1 ☒ | |
| | High | 0.5 ☐ | |
| Procedures | Not available | 50 ☐ | Attachment refers to canister rather than cask, which employs different valve connections and contains inconsistent or missing symbols. |
| | Available, but poor | 5 ☒ | |
| | Nominal | 1 ☐ | |
| | Diagnostic/symptom oriented | 0.5 ☐ | |
| Ergonomics | Missing/Misleading | 50 ☐ | |
| | Poor | 10 ☐ | |
| | Nominal | 1 ☒ | |
| | Good | 0.5 ☐ | |
| Fitness for Duty | Unfit | P(failure) = 1.0 ☐ | |
| | Degraded Fitness | 5 ☐ | |
| | Nominal | 1 ☒ | |
| Work Processes | Poor | 2 ☐ | |
| | Nominal | 1 ☒ | |
| | Good | 0.8 ☐ | |

**B. Calculate the Diagnosis Failure Probability**

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

Diagnosis: 1.0E-2x _1_x_1_x_2_x_1_x_5_x_1_x_1_x_1_=_0.1_ **Diagnosis Failure Probability**

## SPAR-H Human Error Worksheet for LP/SD Operations (Page 2 of 3)

**Plant: Plant X    Initiating Event:______Basic Event : XHE**

**Basic Event Context: Cask Closure**

**Basic Event Description: Operators fail to properly perform vacuum drying system connections and setup.**

## Part II. ACTION

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

| PSFs | PSF Levels | Multiplier for Action | | If non-nominal PSF levels are selected, please note specific reasons in this column |
|---|---|---|---|---|
| Available Time | Inadequate time | P(failure) = 1.0 | ☐ | |
| | Time available ≈ time required | 10 | ☐ | |
| | Nominal time | 1 | ☒ | |
| | Extra time 2-3 x nominal | 0.5 | ☐ | |
| | Expansive Time > 3 x nominal | 0.1 to 0.01 | ☐ | |
| Stress | Extreme | 5 | ☐ | |
| | High | 2 | ☐ | |
| | Nominal | 1 | ☒ | |
| Complexity | Highly complex | 5 | ☐ | Observations of this task suggest moderate complexity for operators. |
| | Moderately complex | 2 | ☒ | |
| | Nominal | 1 | ☐ | |
| Experience/Training | Low | 3 | ☐ | |
| | Nominal | 1 | ☒ | |
| | High | 0.5 | ☐ | |
| Procedures | Not available | 50 | ☐ | Attachment refers to canister rather than cask, which employs different valve connections and contains inconsistent or missing symbols. |
| | Available, but poor | 5 | ☒ | |
| | Nominal | 1 | ☐ | |
| Ergonomics | Missing/Misleading | 50 | ☐ | |
| | Poor | 10 | ☐ | |
| | Nominal | 1 | ☒ | |
| | Good | 0.5 | ☐ | |
| Fitness for Duty | Unfit | P(failure) = 1.0 | ☐ | |
| | Degraded Fitness | 5 | ☐ | |
| | Nominal | 1 | ☒ | |
| Work Processes | Poor | 5 | ☐ | |
| | Nominal | 1 | ☒ | |
| | Good | 0.5 | ☐ | |

**B. Calculate the Action Failure Probability.**

(1) If all PSF ratings are nominal, then the Action Failure Probability = 1.0E-3

(2) Otherwise, Action is 1.0E-3 x Time x Stress x Complexity x Experience/Training x Procedures x Ergonomics x Fitness for Duty x Work Processes

Action: 1.0E-3x _1_x_1_x_2_x_1_x_5_x_1_x_1_x_1_=_0.01 **Action Failure Probability**

## SPAR-H Human Error Worksheet for LP/SD Operations (Page 3 of 3)

**Plant: Plant X        Initiating Event:______ Basic Event : XHE**

## PART III. CALCULATE THE 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, p.1) and the Action Failure Probability (from Part II, p. 2).

Task Failure Without Formal Dependence ($P_{w/od}$)= 0.11        $P_{(w/od)}$= 1.1x10E-1

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## 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 ($P_{w/od}$).

If there is a reason why failure on previous tasks should not be considered, explain here:____________________

### Dependency Condition Table

| Crew (same or different) | Time (close in time or not close in time) | Location (same or different) | Cues (additional or not additional) | Dependency | Number of Human Action Failures Rule ☐ - Not Applicable. Why?________________ |
|---|---|---|---|---|---|
| Same | Close | Same | * | complete | When considering recovery in a series e.g., 2nd, 3rd, or 4th checker |
| | | Different | * | high | |
| | Not Close | Same | No Additional | high | If this error is the **3rd error in the sequence**, then the dependency is at least **moderate**. |
| | | | Additional | moderate | |
| | | Different | No Additional | moderate | If this error is the **4th error in the sequence**, then the dependency is at least **high.** |
| | | | Additional | low | |
| Different | Close | Same | No Additional | moderate | |
| | Not Close | Different | Additional | low | |

* Cue status not a determining feature in this combination of factors.

Using $P_{w/od}$ = Probability of Task Failure Without Formal Dependence (calculated in Part III, p. 3):

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 $P_{w/od}$ using the appropriate values:

(1 + (        *        ))/        = **1.0 Task Failure Probability With Formal Dependence ($P_{w/od}$)**

# 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 – 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. |
| 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. |
| 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 – 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 overdraining 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 – 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 – 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 mgmt 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 informal, poorly planned, ineffective. "Event was primarily the result of breakdown in command and control." |
| 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.<br>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. | Command & control good. 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. |
| 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. | SSS exhibited good command and control while conducting plant restoration. |

# Appendix G
# The Relationship Among SPAR PSFs

**Table G-1. The relationship among SPAR PSFs.**

| Does X affect Y | Available time | Stress | Complexity | Experience/Training | Procedures | Ergonomics | Fitness for Duty | Work Processes |
|---|---|---|---|---|---|---|---|---|
| Available time | 1.0 | Low (amount of stress does not change the available time) | Medium to high (high complexity can make the time available insufficient; lower complexity can reduce memory burdens and make available time sufficient) | 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 or drug abuse may require increased time to decide or act) | Low to moderate (poor shift turn over of information can reduce time available) |
| Stress | High (less time may increase stress) | 1.0 | Medium to high (greater complexity results in higher information demands that can interact with physical or mental stressors) | Medium (more experienced workers may experience less stress or maybe better able to handle the stress they do feel) | Low to medium (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 (inadequate work process can be cumbersome, cause rework, and raise the level of stress for workers) |
| Complexity | Medium to high (little time makes the task more complex, simultaneous acts more difficult to perform) | High (stress can make the situation appear more complex, subjects don't perceive information or perceive less information) | 1.0 | Medium to high (experience can mitigate the effects of complex decisions through heuristics and well-rehearsed 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.) |

| Does X affect Y | Available time | Stress | Complexity | Experience/Training | Procedures | Ergonomics | Fitness for Duty | Work Processes |
|---|---|---|---|---|---|---|---|---|
| Experience/Training | Low (time pressure may cause training sessions to be shorter, smaller amounts of time may have smaller impact on the less experienced) | Medium (affects ability to recall training) | Low (complexity does not influence experience, experience and training can help to mitigate the effect of complexity) | 1.0 | Low (procedures can complement the experience level) | Low (in the best case good ergonomics may serve to assist less well training individuals) | Low (tracking rest or irregular work cycles for duty can reduce the positive effects of training and experience) | Low (poor work processes may somewhat reduce the effectiveness of prior training or experience) |
| Procedures | Medium (small amount of time available may cause personnel to take shortcuts and make errors) | Medium (stress affects information processing capacity) | Medium (high complexity may cause procedures to be more difficult to implement) | Medium (greater experience can overcome poor procedures as well as make the crew doubt them) | 1.0 | Low (ergonomics for situations can make it difficult to follow procedures) | Low (procedures following may be reduced with lower levels of fitness for duty) | Medium (particularly important for procedure design review and implementation) |
| Ergonomics | Low (in general, time does not affect the ergonomics of the scenario) | Low (no known relationship) | Low to medium (high complexity may make marginal ergonomics have a greater impact) | Low (greater experience can mitigate the effects of marginal ergonomics but cannot override) | Low (procedures do not generally influence ergonomics) | 1.0 | Low (no known relationship) | Low (under bad work processes, ergonomics may be neglected) |
| Fitness for duty | Low (any affects are indirect and are accounted for under other PSFs) | Medium to high (in unfit individuals increased stress further compromises performance) | Medium (high complexity may induce fatigue or amplify circadian effects) | Low (for a short while only; high levels of experience can compensate for lower levels of fitness; lack of experience can amplify poor fitness) | Low (robust procedures can aid the performance in cases of lowered fitness for duty) | 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) |
| Work Processes | Medium (time may influence crew interaction and the quality of the interaction) | Medium (stress will affect how the crew communicates and understands information presented, may also designate a positive work culture) | Medium (multi-agent complex tasks require greater coordination) | Medium (experience can help to ease communication, streamline process; less experienced individuals can challenge established work processes) | Medium (procedures can influence the effectiveness or occurrence of work processes) | Low (poor ergonomics in computer interface can result in mistakes while executing various parts of work processes; databases, maintenance, etc.) | 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 |

* Relationship is defined as either low, medium or high.

# Appendix H
# SPAR Development History

**Original Development (1994)**

Efforts directed toward development of the 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, 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 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 the authors' 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 does not consider detail on a finer level than it does. For example, more refined aspects of work processes 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. It is acknowledged that there was a need for a method that was good enough to support the HRA process that could be improved upon as the state-of-the-art in HRA improves.

The existing ASP HRA methodology was developed in 1994 (Blackman and Byers, 1995) and, for clarity and convenience, is hereafter referred to herein as the 1994 ASP HRA methodology. The enhanced and revised version of the methodology, with minor exception is the basis for the SPAR 2002 Version 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. The taxonomy for distinguishing the processing (cognition) portion of a task from the response (action) portion of the task proved somewhat difficult to apply by collaborators who were non-human factors and HRA professionals. 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 provide an accurate analysis.

Standardized Plant Analysis Risk (SPAR) models have been developed by the 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 consisted 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; and
4. Adjust base HEPs based on the review results.

The revision of the 1994 ASP HRA methodology was completed in 1999 by the INEEL 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 2002 with expansion of the screening method to LP/SD scenarios. This report documents the latest version of the SPAR-H method.

**2002 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-H HEPs.

**Distribution of HEPs**

*Previous Approaches to HRA Uncertainty.* Since the 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 $95^{th}$ and $5^{th}$ 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 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 HEPs. Specifically, we utilize the constrained non-informative distribution, which maximizes uncertainty about the mean HEP value. This distribution provides an adequate representation of the upper bound and does not exceed 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 (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.