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U.S. EPR™ Implementation Plan for the Integration of Human Reliability Analysis (HRA) into the Human Factors Engineering (HFE) Program

Technical Report

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Nomenclature

Acronym	Definition
ASEP	Accident Sequence Evaluation Program
CDF	Core Damage Frequency
EPG	Emergency Procedure Guideline
EPRI	Electric Power Research Institute
FA	Functional Allocation
FRA	Functional Requirements Analysis
FSAR	Final Safety Analysis Report
FSS	Full Scope Simulator
FV	Fussell-Vesely importance measure
HA	Human Action
HEP	Human Error Probability
HFE	Human Factors Engineering
HPM	Human Performance Monitoring
HRA	Human Reliability Analysis
HSI	Human-System Interface
IAEA	International Atomic Energy Agency
ISV	Integrated System Validation
LPSD	Low Power and Shut Down
LRF	Large Release Frequency
MCR	Main Control Room
OCS	Operational Conditions Sampling
OER	Operating Experience Review
PICS	Process Information and Control System
PRA	Probabilistic Risk Assessment
PSF	Performance Shaping Factor
RAW	Risk Achievement Worth
SICS	Safety Information and Control System
SMA	Seismic Margin Assessment
SPAR-H	Standardized Plant Analysis Risk–Human Reliability Analysis
V&V	Verification and Validation

1.0 INTRODUCTION

1.1 *Purpose*

The purpose of this Implementation Plan is to provide a method, criteria, and guidance for incorporating the effects and results of the Human Reliability Analysis (HRA), conducted as part of the U.S. EPR™ Probabilistic Risk Assessment (PRA), into the human factors engineering (HFE) program and incorporating design details from the human-system interface (HSI) as input considerations in the HRA.

This integration plan verifies that:

1. Human-error mechanisms are addressed in the design of the HFE aspects of the plant to minimize the likelihood of personnel error, and to allow detection of and recovery from errors.
2. The HRA activity effectively integrates with the HFE program and PRA [1].
3. Operational experience is identified for relevance and fed into the HRA process (NUREG-0933, task HF7 [4]).
4. The HRA is based on proper assumptions concerning details of HSI design, automation, and staffing.

This integration plan provides an approach that is consistent with EPR™ Design Certification Project Quality Assurance Plan [2], the design control procedures, the U.S. EPR™ Project Plan, and applicable regulatory guidance.

1.2 *Scope*

This Implementation Plan includes the method to integrate the HRA process with the design of the HSI and the impact of HFE considerations, particularly safety-related issues, for the U.S. EPR™ design for the HFE design activities.

This plan primarily discusses HRA activities as discussed in Section 7 of NUREG-0711 [3].

Details of the integration of HRA into the HFE program and disciplines are described in Section 3.2.

1.2.1 *HFE Design Activities within the Scope of this Plan*

1.2.1.1 *HFE Program Management [3]*

The HFE Program Management shall coordinate with the PRA / HRA process and verify that needed details are provided to the HRA analyst from all HFE activities to generate the HRA by identifying potentially risk-significant human actions (HA) and design details of the interfaces and operational details that need to be considered. HFE Program Management also verifies that the outputs from the HRA are provided to the HSI design process to help develop HSI designs to mitigate risk-significant HAs and develop appropriate training and to identify activities to be included in the validation program.

1.2.1.2 *Operating Experience Review (OER) [3]*

Operating experience captured by the HFE OER suggesting potentially risk-significant HAs will be provided to the HRA analyst as possible topics requiring HRA analysis. Potentially risk-significant HAs should be provided to the OER team as search topics.

1.2.1.3 *Functional Requirements Analysis (FRA) and Function Allocation (FA) [3]*

System design configurations based on the FRA and FA will result in control system automation that will be considered as input to the HRA. The HRA identifies HAs that have risk-significance. Function Allocation automation decisions should be based, in part, on HRA risk considerations.

1.2.1.4 *Task Analysis [3]*

Task details from the initial task analyses can be used as input to the HRA. The HRA results can be used iteratively to identify tasks that should be modified through interface design changes and/or procedures and training as applicable, if risk-significant issues are identified.

1.2.1.5 *Staffing and Qualifications [3]*

The details considered in Section 6 of NUREG-0711 are used to develop the plant Concept of Operations, which is used as input data for the HRA.

If risk-significant HAs are identified, possible mitigation based on changes in staffing and qualifications may be required.

1.2.1.6 *Human System Interface Design [3]*

The initial HRA considers the conceptual HSI designs. HRA results are then used to consider design modifications when risk-significant HAs along with their performance shaping factors are identified that can be mitigated with interface design modifications.

1.2.1.7 *Procedure Development [3]*

The initial HRA will consider the conceptual plant procedure guidelines. HRA results will then be used to consider procedure modifications when risk-significant HAs are identified that cannot be mitigated with interface design modifications alone.

1.2.1.8 *Training Program Development [3]*

HRA results are used to identify risk-significant HAs that are subject to specific personnel training.

1.2.1.9 *Human Factors Verification & Validation (V&V) [3]*

All risk-significant HAs are addressed as prime sources for specific assessment in the Integrated System Validation (ISV) through the Operational Conditions Sampling (OCS) process.

Situations where human monitoring of an automatic system is risk-significant will also be considered.

Additional factors should be sampled that contribute highly to risk, as defined by the PRA, including:

- Dominant human actions (selected via risk-importance measures and/or sensitivity analyses).
- Dominant accident sequences.
- Dominant systems (selected via PRA-importance measures and/or sensitivity analysis).

1.2.1.10 *Design Implementation [3]*

The U.S. EPR™ HFE program will require developing construction staging and commissioning plans, including use of an interim monitoring and control configurations during construction. These temporary interim configurations will be evaluated from both an operational and engineering perspective. This is considered more fully during the design implementation phase. Activities determined to be risk-significant from the HRA will be addressed when developing the various interim plant monitoring and control configurations.

1.2.2 *HFE Design Activities outside the Scope of this Plan*

1.2.2.1 *Human Performance Monitoring (HPM) [3]*

Although not within the scope of this plan, ongoing monitoring of operating experience once the plant is operational should be used to validate and update HRA results and generate operating experience which could lead to proposed plant modifications.

The review process of future proposed modifications after commissioning includes HFE screening and use of HRA data, when applicable.

1.3 *Applicability*

This Implementation Plan applies to U.S. EPR™ design activities; specifically, the human factors engineering design and the human reliability analysis processes.

1.4 *Owner*

The Program Manager, Human Factors Engineering (HFE) is responsible for providing this implementation plan.

1.5 *Definition of Terms*

Within this document, unless otherwise noted, HFE program terminology conforms with the usage established in NUREG-0711, [3].

The following definitions apply to special terms used within this document:

Design Implementation	The detailed plan and schedule to construct and commission the plant, main control room (MCR) and HSI facilities. This plan, as described in Section 12 of NUREG-0711, identifies concerns during the various interim stages that may be required during construction prior to actually commissioning and turning over the final MCR and HSI envisioned in the HSI Design process.
Human Action (HA)	A manual action completed by a person in order to accomplish a task.
Human Error Probability (HEP)	A measure of the likelihood that various failure modes for plant personnel to obtain the correct, required, or specified action or response in a given situation. The HEP is the probability of the human failure event
Human System Interface (HSI)	A human-system interface (HSI) is that part of the system through which personnel interact to perform their functions and tasks. As defined in regulatory documents, in addition to the actual operator interfaces, HSI also includes procedures and considers training.
HSI Design Implementation (Plan)	The activities required to complete the design of the MCR and HSI as described in section 8 of NUREG-0711. (See *Design Implementation*)

Plant Safety – also called "*safe operation of the plant.*"	A general term used herein to denote the technical safety objectives as articulated by the International Nuclear Safety Advisory Group of the International Atomic Energy Agency (IAEA) in the "Basic Safety Principles for Nuclear Power Plants" (IAEA, 1988): "To prevent with high confidence accidents in nuclear plants; to verify that, for all accidents taken into account in the design of the plant, even those of very low probability, radiological consequences, if any, would be minor; and to provide reasonable assurance that the likelihood of severe accidents with serious radiological consequences is extremely small."
Performance Shaping Factors (PSFs)	Factors that influence human reliability through their effects on performance. PSFs include factors such as environmental conditions, human-system interface design, procedures, training, and supervision.
HRA Analyst	In the design process, an analyst in the reliability / availability engineering discipline specifically performing HRA analyses as part of the PRA program, as described in section 7 of NUREG-0711.
Risk-Important Human Actions	Actions that are performed by plant personnel to provide reasonable assurance of plant safety. Actions may be made up of one or more tasks. There are both absolute and relative criteria for defining risk important actions. From an absolute standpoint, a risk important action is any action whose successful performance is needed to provide reasonable assurance that probabilistic design objectives are met. From a relative standpoint, the risk important actions may be defined as those with the greatest risk contribution in comparison to all risk contributors. The identification can be done quantitatively using standard risk important measures derived from risk analysis and qualitatively from various criteria such as task performance concerns based on the consideration for performance shaping factors. *Note: This term and definition is as used in NUREG-0711. U. S. EPR™ documentation and this plan typically use the term "risk-significant" as defined below. These terms are synonymous.*

Risk- Significant Human Action	Actions that are performed by plant personnel to provide reasonable assurance of plant safety. Actions may be made up of one or more tasks. However, this designation shows that the actions have been evaluated and found to be above set criteria. These Human Actions have a Fussell-Vesely (FV) value [ ]. Examples of Risk Significant Human Actions are located in Appendix A. The individual scores for each event type can be found in FSAR chapter 19.

1.6 *Background*

The HRA is an iterative process. This is intended to start at the beginning of the design process and to continue through the design lifecycle. The HRA is intended to be an interactive process with the HFE processes.

This integration plan shall be used in accordance with AREVA NP's procedures and policies.

HRA evaluates the potential for human error that may affect plant safety. Thus, HRA is an essential element in achieving the HFE design goal of providing a design that helps verify that human performance during actual plant operation matches PRA predictions.

HRA considers several factors that affect human performance including accident analyses (indicating time available for action), task analyses, procedures, and HSI design. Through this analysis, the HFE design is confirmed to provide adequate support to the operational staff when monitoring critical plant processes and executing risk-significant actions. Also, the HRA provides reasonable assurance that these control activities are accomplished with success probabilities consistent with those associated with the PRA. Outputs from the HFE processes combined with operating experience are fed back through the PRA/HRA.

1.7 *Interfaces*

The integration of HRA into the HFE program and disciplines is described within Section 3.1 and 3.4 below:

2.0 CODES, STANDARDS, AND REGULATIONS

NUREG-0711, "Human Factors Engineering Program Review Model", Rev.2 – 02/2004.

NUREG-0800, Standard Review Plan Section 18.0, "Human Factors Engineering", Rev 1 – 02/2004.

NUREG-0933, "A Prioritization of Generic Safety Issues", September 2007.

NRC Regulatory Guide 1.206, Section C.I.18.6.1, Human Reliability Analysis, June 2007.

3.0 METHODOLOGY

3.1 *General Requirements*

The HRA is an integral activity within the U.S. EPR™ PRA. The HRA is an engineering activity that supports both the HFE design and PRA activities. These activities are also closely associated with the emergency procedure guideline (EPG) development. These supportive relationships are described within this document. For the purposes of this document, the collaboration of HRA, HFE, and EPG development efforts will be called the Integration Design. Figure 3-1 shows the relationship of HRA with the other elements within the HFE design process. The various pathways of information exchange can be seen from the solid lines. The arrows show the direction of expected information exchange. Task analysis is expected to give and receive information.

The HRA is performed iteratively during the design process. The quality of the HRA depends on the analyst's understanding of personnel tasks, the information related to those tasks, and the factors that influence human performance of those tasks. Continuous development of information to facilitate the understanding of causes and modes of human error is necessary to minimize the likelihood of creating designs conducive to personnel error and that such design errors are detected and corrected. The HRA uses descriptions and analyses of operator functions and tasks, as well as the operational characteristics of HSIs. HRA provides valuable insight into desirable characteristics of the HSI design. The HFE design effort gives special attention to those plant scenarios, risk-significant HAs, and HSIs that have been identified by PRA/HRA as being important to plant safety and reliability. These risk-significant insights are specifically addressed within the U.S. EPR™ HFE Program. Section 3.2 describes how HRA integrates with the other HFE elements. This integration verifies that risk-significant HAs are well supported by the applicable U. S. EPR™ HFE design and are within acceptable human performance capabilities. Identification of the risk-significant HAs is also an essential input to the human factors Verification and Validation (V&V)

process [5] . HRA effectively integrates the HFE program and the PRA. New items analyzed during the design process determined through HRA to have a risk-significance value that is higher than the indicated threshold levels, listed in Section 3.1.1, are sent back through the HFE design process along with the applicable performance shaping factors as candidates for design changes.

Personnel with operating experience will use a plant-specific Full-Scope Simulator (FSS) to perform walkthrough analyses to validate HRA assumptions (e.g., decision making and diagnosis strategies for dominant sequences). Reviews from these analyses are incorporated into subsequent iterations of the HRA/PRA.

3.1.1 *Risk-Significant Human Actions (HAs)*

Risk-significant HAs in the initial or modified HSI design are identified by the PRA. Examples of HRA risk-significant HAs for the U.S. EPR™ can be found in Appendix A. Additional potentially risk-significant HAs may be identified through operating experience and HFE task analysis and delivered to PRA for analysis. These are HAs that are either important contributors to overall plant risk, or that may become important to plant risk if reliability is degraded. Identification of risk-significant HAs is a direct product of the Level 1 and Level 2 PRA results from U.S. EPR™ FSAR Tier 2, Chapter 19 (e.g., HAs such as manual initiation of feed and bleed).

The results of the Level 1 PRA include an interpretation of risk-significance using Fussell-Vesely (FV) and Risk Achievement Worth (RAW) importance methods. These standard risk-significance metrics are used to rank the dominant risk contributors in the categories of equipment failures and human errors. They also rank the importance of initiating events and accident sequences. Human errors (and component failures) are considered risk-significant if they meet either of the following criteria:

[ ]

A value of FV greater than [ ] indicates the failure contributes more than [ ] of the total core damage frequency (CDF). A value of RAW greater than [ ] indicates that the CDF would at least double if the HA were guaranteed to fail. Taken together, these two risk importance measures signify both the relative importance of the component or operator action to overall plant risk (FV), as well as the importance of maintaining the reliability of the component or operator action (RAW).

Similar risk-importance metrics are produced by the Level 2 PRA results, except that the criterion for risk-significance is associated with large release frequency (LRF) instead of CDF. Human errors (and component failures) are considered risk-significant if they meet either of the following criteria:

[ ]

Failure probabilities for HAs are estimated in the HRA section of the PRA [1]. The HRA considers two types of human actions:

- Pre-initiator actions: actions that, if not performed correctly, can leave equipment or systems unavailable to respond to a demand created by an initiating event.
- Post-initiator actions: actions that are performed to initiate or control the function of a system, or to compensate for a system failure (e.g., by realigning a system) in order to mitigate an initiating event.

[ ]

Performance Shaping Factors (PSFs) are used in human reliability prediction methodologies to adjust base HEPs to account for conditions that may affect the probability of error. The relationship of HEPs with the HRA process, including PSF mitigation actions, is shown in Figure 3-2. General flow chart of the HFE/HRA procedures, and control room ergonomics. The values for the PSFs are often assigned using subjective judgment, especially in the early stages of the design. The intent of the HFE/HRA implementation plan is to identify risk-significant HAs, and influence the HFE design process and EPG development during the detailed design process to improve

the PSFs for those actions. This process cannot eliminate the subjectivity in the PSF values, but it reduces the uncertainty in the HEP estimates and increase confidence in the operator reliability.

Figure 3-1: Relationship of HRA in the HFE Program (Adapted from Figure 7.1 of NUREG-0711, Rev. 2)

3.2 *Responsibilities*

3.2.1 *Human Factors Specialist(s)*

Provides the HRA analyst(s) with applicable details concerning HSI and expected tasks and operations.

Completes the HFE design paying focusing on interfaces associated with risk-significant HAs as identified by the HRA Engineer.

3.2.2 *HRA Analyst(s)*

Receives applicable input details concerning HSI and expected tasks and operations required to perform the HRA from the HFE design team(s), operations, and technical managers.

Provides the HFE specialist(s) with HRA basis and results, identifying risk-significant tasks where particular attention should be provided in the design of the associated HSI.

3.2.3 *Technical Manager(s)*

Provides approval prior to transmission of the documents that are exchanged between the HFE or HRA engineer for which they are responsible.

3.2.4 *Systems and I&C Engineer(s)*

Provides the HFE specialist(s) and HRA analyst(s) with initial functional requirements and function allocation (automation) decisions for individual systems and details of system operations and expected tasks.

Receives recommendations from the HRA analyst when changes to automation levels are needed due to risk considerations.

3.2.5 *Operations Specialist(s)*

Consults with HRA analyst(s) as required to identify potentially risk-significant HAs and effects of known PSFs. For the purposes of this procedure these personnel will be considered a subset of the HFE design team.

3.2.6 *Procedure Developer(s)*

Completes EPGs and provides them to the HFE for the HSI design and to the HRA to complete analysis.

Receives recommendations from the HRA analyst(s) identifying potentially risk-significant HAs that may require more detailed procedure steps.

3.2.7 *Personnel Training Developer(s)*

Receives recommendations from the HRA analyst(s) identifying potentially risk-significant HAs that may require more detailed training and identification of specific knowledge and skills required.

3.2.8 *Maintenance / Inspection Specialists*

Provides HFE specialist(s) and HRA analyst(s) advice concerning proposed equipment with potential maintenance / inspection problems.

Receives recommendations from the HRA analyst(s) identifying components with maintenance-related risk-significant HAs so that less error-prone designs for maintenance can be considered.

3.3 *Methodology*

The HFE design gives special attention to those plant scenarios, risk-significant HAs, and HSIs that have been identified by PRA/HRA as being important to plant safety and reliability. The U.S. EPR™ HFE/ HRA integrated HSI design process is described below.

The HRA evaluates and identifies specific HAs based on the impact of potential errors on plant safety. This evaluation is iterative and begins early in the design process and continues throughout all phases of the design. The initial HRA uses a set of scenarios and accident sequences that contribute to CDF or LRF. From these inputs, HEPs are calculated and are influenced by PSFs. The HRA will therefore consider operating experience, MCR staffing, training, and other assumptions to adjust the base HEPs to account for conditions which could affect plant operation and human performance (e.g., the complexity of the accident and the stress upon the operators).

As the U.S. EPR™ plant and interface designs develop, the HRA model is refined to incorporate other HFE elements that will affect human performance. This includes the functional requirements analysis, functional allocation, task-analysis, procedures, training, and human system interface design. These elements influence the HEP estimates through the PSF values, and the PRA evaluates the impact of these errors on accident scenarios. The HRA supports the HFE by providing the HSI design team with feedback identifying where additional design effort has high potential for minimizing personnel errors that have high risk-significance and improving operator recovery from human errors and plant system failures.

The HFE design is refined as appropriate to improve the HEP value. This is accomplished by adjusting the HSI design, the sequence of actions of the EPG, the plant systems design (i.e., functional allocation and automation changes to the associated mechanical, fluid and electrical systems), the procedures, and/or the training provided operational and technical maintenance personnel.

During V&V, HRA assumptions are assessed and validated. In addition, HRA input is used in the OCS process to select the evolutions and scenarios that are to be assessed during the ISV in the FSS as the final part of the HFE V&V process. The HRA model is updated based on the validation results.

During the design process, consideration should be given to the effects of modifications on the existing HRA. These can occur because of changes to plant systems such as those made through task analysis, HSI design, procedures, or training. All inputs to HRA from task analysis is considered as the design progresses. Personnel interactions can affect the rest of the plant. These considerations should include:

When the final desired plant configuration, including the HSI, has been developed, a design implementation plan shall be developed for the actual plant construction and commissioning. This may require staged processes with temporary interim control room configurations. Separate HFE assessments of such interim configurations will need to be performed, and HRA analyses may be required to verify that no interim configurations result in situations where the resulting control systems would have an unacceptable plant risk.

When the plant is commissioned and turned over to the owner/customer, a human performance monitoring program should be established, which may result in updating HRA models and values. Such a human performance monitoring program is outside of the scope of the HRA and HFE design program described in this implementation plan.

Figure 3-2: General Flow Chart of the HFE / HRA Integration Process

3.4 *HRA-HFE Integration Implementation*

The HRA program evaluates potential human errors as a part of the HFE design process. This process is shown in Figure 3-2. Human error analysis involves many aspects of the HFE design (see Figure 3-1), and therefore certain elements of the HFE design shall be developed in order for the human error analysis to be effective. At a minimum, the task analysis and staffing analysis should be completed based on the concept of operations. The HSI should be designed to a level that will be able to support the error analysis. This includes the completion of the HSI Style Guide [8], and the hierarchy and navigation for PICS, SICS and alarms.

4.0 RESULTS AND DOCUMENTATION

The results of the HRA implementation plan will be combined in a final summary report.

The summary report identifies the following:

- A list of risk–significant HAs, dominant accident sequences, dominant systems, and summary of how those HAs and the associated tasks and scenarios are addressed during the various parts of the HFE design process.
- How risk-significant HAs were incorporated into the design in order to minimize human errors and make the system error tolerant by enabling error detection and recovery.
- Training and procedures that detail how to prevent errors, and how to recover if they occur.
- A description of how HRA assumptions were validated during the design process.
- A validation of specific HRA assumptions made for the EPGs.

This final report will form the basis for verifying that HRA can be used during plant operation to assess potential changes. The HRA summary will assist in prioritizing risk-significant corrective actions during HPM.

5.0 REFERENCES

1. AREVA NP Document, "Human Reliability Analysis (HRA)."

2. AREVA NP Document, "Quality Assurance Plan (QAP) for Design Certification of the U.S. EPR™."

3. NUREG-0711, Rev. 2, "Human Factors Engineering Program Review Model," 2004.

4. NUREG-0933, "A Prioritization of Generic Safety Issues", September 2007

5. AREVA NP Document, "U.S. EPR Human Factors Verification and Validation Implementation Plan."

6. "The EPRI HRA Calculator", Version 3.04, EPRI and Scientech, Copyright © 2006 Electric Power Research Institute, Inc.

7. EPRI Report 1008122, "Human Factors Guidance for Control Room and Digital Human-System Interface Design and Modification", November 2004

8. AREVA NP Document, "EPR Human System Interface Design Style Guide."

9. AREVA NP Document, "U.S. EPR Functional Requirements Analysis and Functional Allocation Implementation Plan."

10. AREVA NP Document, "U. S. EPR™ Task Analysis Implementation Plan."

11. AREVA NP Document, "U.S. EPR Human System Interface Design Implementation Plan."

12. AREVA NP Document, "U.S. EPR™ Human Factors Procedure Implementation Plan."

APPENDIX A U.S. EPR™ HRA RISK-SIGNIFICANT HUMAN ACTIONS

Table A-1: Examples of U.S. EPR™ Risk-Significant Human Actions for At-Power Modes [ ]

Table A-2: Examples of U.S. EPR™ Risk-Significant Human Actions for Low Power and Shutdown Modes [ ]