NUREG-0711, Rev. 1

Human Factors Engineering Program Review Model

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Human Factors Engineering Program Review Model

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ABSTRACT

This document is used by the staff of the Nuclear Regulatory Commission to review the human factors engineering (HFE) programs of applicants for construction permits, operating licenses, standard design certifications, combined operating licenses, and for license amendments. The purpose of these reviews is to help ensure safety by verifying that accepted HFE practices and guidelines are incorporated into the applicant's HFE program. The review methodology provides a basis for performing reviews that address the twelve elements of an HFE program: HFE Program Management, Operating Experience Review; Functional Requirements Analysis and Function Allocation, Task Analysis, Staffing, Human Reliability Analysis, Human-System Interface Design, Procedure Development, Training Program Development, Human Factors Verification and Validation, Design Implementation, and Human Performance Monitoring. Each review element is divided into four sections: Background, Objective, Applicant Submittals, and Review Criteria. References to sources of additional information are also provided for each element.

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EXECUTIVE SUMMARY

Nuclear power plant (NPP) personnel play a vital role in the productive, efficient, and safe generation of electric power. Operators monitor and control plant systems and components to ensure their proper functioning. Test and maintenance personnel help ensure that plant equipment is functioning properly and restore components when malfunctions occur.

The human factors engineering (HFE) staff of the Nuclear Regulatory Commission's (NRC's) Office of Nuclear Reactor Regulation (NRR) evaluates HFE programs of applicants for construction permits (CPs), operating licenses (OLs), standard design certifications (DCs), combined operating licenses (COLs), and for license amendments. The purpose of these reviews is to help ensure public health and safety by verifying that accepted HFE practices and guidelines are incorporated into the applicant's HFE program. The HFE review includes the design process, the final design, its implementation, and ongoing performance monitoring. Therefore, these reviews help ensure public health and safety by verifying that accepted HFE practices and guidelines are incorporated into the design.

The HFE aspects of the plant should be developed, designed, and evaluated on the basis of a structured systems analysis using accepted HFE principles. Therefore, the review method reflects a top-down approach for conducting an NRC safety evaluation so that the significance of individual topics may be seen in relationship to the high-level goal of plant safety. Top-down refers to an approach starting at the "top" with the plant's high-level mission goals and dividing them into the functions necessary to achieve the goals. Functions are allocated to human and system resources and are separated into tasks. Personnel tasks are analyzed to identify the alarms, displays, procedures, and controls that will be required for task performance. Tasks are arranged into meaningful jobs and the human-system interface (HSI), procedures, and training are designed to best support them. The detailed design (of the HSI, procedures, and training) is the "bottom" of the top-down process. The HFE safety evaluation is broad-based and includes normal and emergency operations, maintenance, test, inspection, and surveillance activities.

The HFE Program Review Model consists of twelve review elements. Each element is divided into four sections: Background, Objective, Applicant Submittals, and Review Criteria.

- *Background* - A brief explanation is given of the rationale and purpose of each element.
- *Objective* - The review objective(s) of the element is defined.
- *Applicant Submittals* - Materials to be provided for the NRC's review are listed.
- *Review Criteria* - The acceptance criteria for the review elements are provided.

References to sources of additional information are also provided for each element.

An overview of each of the review elements follows.

HFE Program Management

The overall purpose of the HFE program review is to ensure that

- the applicant has integrated HFE into the plant's development, design, and evaluation

- the applicant has provided HFE products (e.g., HSIs, procedures, and training) that make it possible to perform operation, maintenance, test, inspection, and surveillance tasks safely, efficiently, and reliably
- the HFE program and its products reflect "state-of-the-art human factors principles" [10 CFR 50.34(f) and 10 CFR 52.47(a)(1)(ii)] and satisfy all specific regulatory requirements

The objective of this review element is to ensure that the applicant has an HFE design team with the responsibility, authority, placement within the organization, and composition to ensure that the design commitment to HFE is met. Also, the team should be guided by a plan to ensure that the HFE program is properly developed, executed, overseen, and documented. This plan should describe the technical program elements ensuring that all aspects of the HSI, procedures, and training are developed, designed, and evaluated on the basis of a structured top-down systems analysis using accepted HFE principles.

Operating Experience Review

The main purpose of conducting an operating experience review (OER) is to identify HFE-related safety issues. The OER should provide information on the past performance of predecessor designs. In the case of new plants this may be earlier designs on which the new design is based. In the case of plant modifications, it may be the design of the systems being changed. The issues and lessons learned from operating experience provide a basis for improving the plant design in a timely way; i.e., at the beginning of the design process.

The objective of this element is to assure that the applicant has identified and analyzed HFE-related problems and issues in previous designs that are similar to the current design under review. In this way, negative features associated with predecessor designs may be avoided in the current one while retaining positive features. The OER should address the predecessor systems upon which the design is based, selected technological approaches (e.g., if touch-screen interfaces are planned, the HFE issues associated with using them should be reviewed), and the plant's HFE issues (e.g., generic safety issues defined by the NRC).

Functional Requirements Analysis and Function Allocation

The purpose of this review element is to ensure that the applicant has defined the plant's safety functional requirements and that the function allocations take advantage of human strengths and avoid allocating functions that would be negatively affected by human limitations. The operator's role is examined in two steps: functional requirements analysis, and function allocation (assignment of levels of automation).

Functional requirements analysis is the identification of those functions which must be performed to satisfy the plant's safety objectives, i.e., to prevent or mitigate the consequences of postulated accidents that could cause undue risk to the health and safety of the public. This analysis determines the objectives, performance requirements, and constraints of the design, and sets a framework for understanding the role of controllers (whether personnel or system) in regulating plant processes.

Function allocation is the analysis of the requirements for plant control and the assignment of control functions to (1) personnel (e.g., manual control), (2) system elements (e.g., automatic control and passive, self-controlling phenomena), and (3) combinations of the two (e.g., shared control and automatic systems

with manual backup). Plant safety and reliability are enhanced by exploiting the strengths of personnel and system elements, including improvements that can be achieved through assigning control to these elements with overlapping and redundant responsibilities. Function allocation should be based upon HFE principles using a structured and well-documented methodology that provides personnel with logical, coherent, and meaningful tasks.

Task Analysis

Task analysis is the identification of task requirements for accomplishing the functions allocated to plant personnel. The objective of a task analysis review is to ensure that the applicant's task analysis identifies the requirements of the tasks that personnel must perform. The task analysis should (1) provide one of the bases for making decisions on design, (2) assure that human-performance requirements do not exceed human capabilities, (3) be used as basic input for developing procedures, (4) be used as basic information for developing the staffing, training, and communication requirements of the plant, and (5) form the basis for specifying the requirements for the displays, data processing, and controls needed to carry out tasks.

Staffing and Qualifications

Plant staffing and their qualifications are important consideration throughout the design process. Initial staffing levels may be established early in the process based on experience with previous plants, staffing goals (such as for staffing reductions), initial analyses, and government regulations. However, the acceptability of the staffing goals and assumptions should be examined as the design of the plant proceeds. The objective of the staffing review is to ensure that the applicant has systematically analyzed the requirements for the number and qualifications of personnel that includes a thorough understanding of task requirements and regulatory requirements.

Human Reliability Analysis

Human reliability analysis (HRA) seeks to evaluate the potential for, and mechanisms of, human error that may affect plant safety. Thus, it is an essential element in achieving the HFE design goal of providing operator interfaces that will minimize personnel errors, allow their detection, and provide recovery capability. The HRA should be conducted as an integrated activity to support both the HFE design and probabilistic risk assessment (PRA). The PRA and HRA should be performed early in the design process to provide insights and guidance both for systems design and for HFE purposes. The robustness of the HRA depends, in large part, on the analyst's understanding of personnel tasks, the information related to them, and the factors which influence human performance. Accordingly, the HRA might be carried out interactively as the design progresses. By developing an understanding of the causes, modes, and probabilities of human error, the HRA can provide valuable insights into the desirable characteristics of the HSI design; consequently, special attention should be paid to those scenarios, critical human actions, and HSI components that were identified by HRA and PRA analyses as being important to the plant's safety and reliability.

The objectives of this review element are to ensure that (1) the applicant has addressed human-error mechanisms in the design of the HFE aspects of the plant to minimize the likelihood of personnel error, and ensure errors are detected and recovered from; and (2) the HRA activity effectively integrates the HFE program with the PRA and risk analysis.

Human-System Interface Design

The objective of this review element is to evaluate the process by which HSI design requirements are developed and HSI designs are identified and refined. The review should ensure that the applicant has appropriately translated functional and task requirements to the detailed design of alarms, displays, controls, and other aspects of the HSI. The HSI should be designed using a structured methodology that should guide designers in identifying and selecting candidate HSI approaches, defining the detailed design, and performing HSI tests and evaluations. It should cover the development and use of HFE guidelines that are tailored to the unique aspects of the applicants's design, e.g., a style guide to define the design-specific conventions. The availability of an HSI design methodology will help ensure standardization and consistency in applying HFE principles. The process and the rationale for the HSI design should be documented for review (including the results of trade-off studies, other analyses and evaluations, and the rationale for choosing design and evaluation tools).

Procedure Development

Procedures are essential to plant safety because they support and guide personnel interactions with plant systems and their response to plant-related events. Procedures should be developed from the same design process and analyses as the HSIs and training. This will result in a well-integrated design with a high-degree of consistency. The objective of the review is to ensure human engineering principles and guidance is applied, along with all other design requirements, to develop procedures that are technically accurate, comprehensive, explicit, easy to use, and validated.

Training Program Development

The NRC requires a systems approach to training and also requires that it be based on the systematic analysis of job and task requirements. The HFE analyses provide a valuable understanding of such task requirements. The objective of the training review is to ensure that the applicant establishes an approach for developing personnel training that incorporates the elements of a systems approach, and

- evaluates the knowledge and skill-requirements of personnel
- coordinates the development of the training program with the other elements of the HFE design process
- implements the training effectively in a manner consistent with human factors principles and practices

Human Factors Verification and Validation

Verification and validation (V&V) evaluations comprehensively determine that the final design conforms to HFE design principles, and enables personnel to successfully and safely perform their tasks to achieve operational goals. This element involves three evaluations, the objectives of which are to assure the following:

- HSI Task Support Verification is an evaluation to verify that the HSI supports personnel task requirements as defined by task analyses.

- HFE Design Verification is an evaluation to verify that the HSI is designed to accommodate human capabilities and limitations as reflected in HFE guidelines such as those provided in NUREG-0700.
- Integrated System Validation is an evaluation using performance-based tests to determine whether an integrated system design (i.e., hardware, software, and personnel elements) meets performance requirements and acceptably supports safe operation of the plant.

These evaluations identify human engineering discrepancies (HEDs). The staff's review of the applicant's HED resolution is an activity that can be performed iteratively with V&V. HED resolution review ensures that the applicant has assessed the importance of HEDs, corrected important HEDs, and that the results are confirmed to be acceptable.

Design Implementation

This element addresses implementation of the HFE aspects of the plant design for both new plants and plant modifications. For a new plant, the implementation phase is well defined and carefully monitored through start-up procedures and testing; implementation of plant modifications is more complex.

The objectives of this review element are to ensure that:

- the applicant's implementation of modernized plant systems, HSIs, procedures, and training considers their effect on personnel performance and provides the necessary support to ensure safe operations
- the applicant's as-built design conforms to the verified and validated design that resulted from the HFE design process.

Human Performance Monitoring

A human performance monitoring strategy will help to ensure that the confidence developed by the completion of the integrated system validation is maintained over time. There is no intent to periodically repeat the full integrated system validation; however, there should be sufficient evidence to provide reasonable confidence that personnel have maintained the skills necessary to accomplish the assumed actions.

The objective of this review is to provide assurance that the applicant has prepared a human performance monitoring strategy for ensuring that no safety degradation occurs because of any changes that are made in the plant and to provide assurance that the conclusions that have been drawn from the evaluation remain valid over time.

ACRONYMS

ALWR	advanced light water reactor
ANS	American Nuclear Society
ANSI	American National Standards Institute
ATWS	anticipated transients without scram
BNL	Brookhaven National Laboratory
CAP	corrective action program
CAS	central alarm station
CFR	U.S. Code of Federal Regulations
COL	combined operating license
CP	construction permit
CR	control room
DAC	design acceptance criteria
DBA	design basis accident
EOF	emergency offsite facility
EOP	emergency operating procedure
EPG	emergency procedure guideline
EPRI	Electric Power Research Institute
GDC	General Design Criteria
GTG	generic technical guidelines
HA	human action
HED	human engineering discrepancies
HFE	human factors engineering
HRA	human reliability analysis
HSI	human-system interface
I&C	instrumentation and control
IAEA	International Atomic Energy Agency
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Standards Organization
ITAAC	inspections, tests, analyses, and acceptance criteria
LCS	local control station
LER	licensee event report
LOCA	loss-of-coolant accident
MCR	main control room
MUX	multiplexer
NASA	National Aeronautics and Space Administration
NEI	Nuclear Energy Institute
NPP	nuclear power plant
NRC	Nuclear Regulatory Commission
NRR	Office of Nuclear Reactor Regulation (NRC)
OER	operating experience review
OL	operating license
PRA	probabilistic risk assessment
PSF	performance shaping factor
RCS	reactor coolant system

RG	regulatory guide (NRC)
SAR	safety analysis report
SAS	secondary alarm station
SGTR	steam generator tube rupture
SPDS	safety parameter display system
SRP	Standard Review Plan
SSAR	standard safety analysis report
SSC	structure, system, and component
TMI	Three Mile Island
TR	technical report
TSC	technical support center
UFSAR	updated final safety analysis report
URD	utility requirements document
V&V	verification and validation

1 INTRODUCTION

1.1 Background

Nuclear power plant (NPP) personnel play a vital role in the productive, efficient, and safe generation of electric power. Operators monitor and control plant systems and components to ensure their proper functioning. Test and maintenance personnel help ensure that plant equipment is functioning properly and restore components when malfunctions occur. One of the important insights from studies of the Three Mile Island (TMI), Chernoybl, and other NPP events is that errors resulting from human factors deficiencies such as poor control room design, procedures, and training are a significant contributing factor to NPP incidents and accidents.

Ensuring plant safety requires "defense in depth." Defense in depth includes the use of multiple barriers to prevent the release of radioactive materials and uses a variety of programs to ensure the integrity of barriers and related systems (IAEA, 1988). These programs include conservative design, quality assurance, administrative controls, and human factors. Human factors plays a significant role in supporting plant safety and providing defense in depth.

The human factors engineering (HFE) staff of the Nuclear Regulatory Commission's (NRC's) Office of Nuclear Reactor Regulation (NRR) evaluates HFE programs of applicants for construction permits (CPs), operating licenses (OLs), standard design certifications (DCs), combined operating licenses (COLs), and for license amendments. In this document, the term "applicant" is subsequently used to succinctly refer to both licensees and applicants for design certification or plant licensing. The purpose of these reviews is to help ensure public health and safety by verifying that accepted HFE practices and guidelines are incorporated into the applicant's HFE program. The HFE reviews include the design process, the final design, its implementation, and ongoing performance monitoring. Therefore, these reviews help ensure public health and safety by verifying that accepted HFE practices, standards, and guidelines are incorporated into the design.

General guidance to the staff for the performance of HFE reviews is in Chapter 18 of the Standard Review Plan, NUREG-0800 (NRC, 1996). This document, the *Human Factors Engineering Program Review Model* (NUREG-0711), supports the staff's HFE reviews by providing detailed review criteria. The review process reflects a "top-down" approach to the conduct of an HFE program safety evaluation. "Top-down" refers to the fact that the review approach starts at the "top" with high-level plant mission goals. These goals are divided into the functions necessary to achieve the mission goals. Functions are allocated to human and system resources and are separated into tasks for the purposes of specifying the alarms, information, and controls that will be needed to accomplish function assignments. Tasks are arranged into meaningful jobs and the human-system interfaces (HSIs), procedures, and training are designed to support job task performance. The detailed design of the HSIs, procedures, and training is the bottom of the "top-down" process. The HFE safety evaluation is broad-based and includes normal and emergency operations, maintenance, test, inspection, and surveillance activities.

NRC regulations in 10CFR Parts 50 and 52 require a variety of control and displays to be used by operators. They also require a control room that reflects state-of-the-art human factors principles. This document provides detailed guidance for NRC staff to use in verifying that these requirements are met.

NUREG-1649 (NRC, 2000) describes the NRC's Reactor Inspection and Oversight Program. This program is outlined using "cornerstones" for reactor safety, radiation safety, and security. They are initiating events, mitigation systems, barrier integrity, and emergency preparedness. Well-designed HSIs,

procedures and training are important to optimizing each of these four cornerstones and the guidance contained herein will help to ensure that they are well-designed. They are also important to help ensure the radiation safety cornerstone goals of minimizing the radiation exposure of plant workers and the general public during routine operations. Additionally, these guidelines could be applied to the plant security program's central alarm station (CAS) and secondary alarm station (SAS) in order to improve their functionality. In addition, there are three cross-cutting elements; one of which is human performance, and supporting human performance is one of the principal aspects of this document.

An applicant's HFE program best ensures plant safety when it is: (1) developed by a qualified HFE design team with all skills, using an acceptable HFE program plan; (2) the result of appropriate HFE studies and analyses that provide accurate and complete inputs to the design process and inputs to verification and validation (V&V) assessment criteria; (3) designed using proven technology based on human performance and task requirements incorporating accepted HFE standards and guidelines; (4) evaluated with a thorough V&V test program; (5) implemented in a manner that effectively supports operations; and (6) monitored after operations to detect changes in safe performance standards.

1.2 General Description of the Program Review Model

1.2.1 Review Elements

This document is organized into twelve elements arranged in four general activities as shown in Figure 1.1. A brief description follows of the review objectives, acceptance criteria, and applicant products reviewed for each element. The review elements are described in more detail in remaining sections of this report.

Each element is divided into four sections: Background, Objective, Applicant Submittals, and Review Criteria.

(1) *Background* - A brief explanation of the rationale and purpose is provided for each element.

(2) *Objective* - The review objective(s) of the element is defined.

(3) *Applicant Submittals* - In general, applicants are expected to submit two reports for NRC review:

- An *implementation plan* gives the applicant's proposed methodology for meeting the acceptance criteria of the element. An implementation plan review gives the applicant the opportunity to obtain staff review of and concurrence in the applicant's approach before conducting the activities associated with the element. Such a review is desirable from the staff's perspective because it provides the opportunity to resolve methodological issues and provide input early in the analysis or design process when staff concerns can more easily be addressed than when the effort is completed.
- A *results summary report* gives the results of the applicant's efforts related to each element. The NRC staff will use the report as the main source of information for assessing the applicant's efforts using the review criteria contained in this document.

This information may be submitted in a form other than in two reports. In some cases

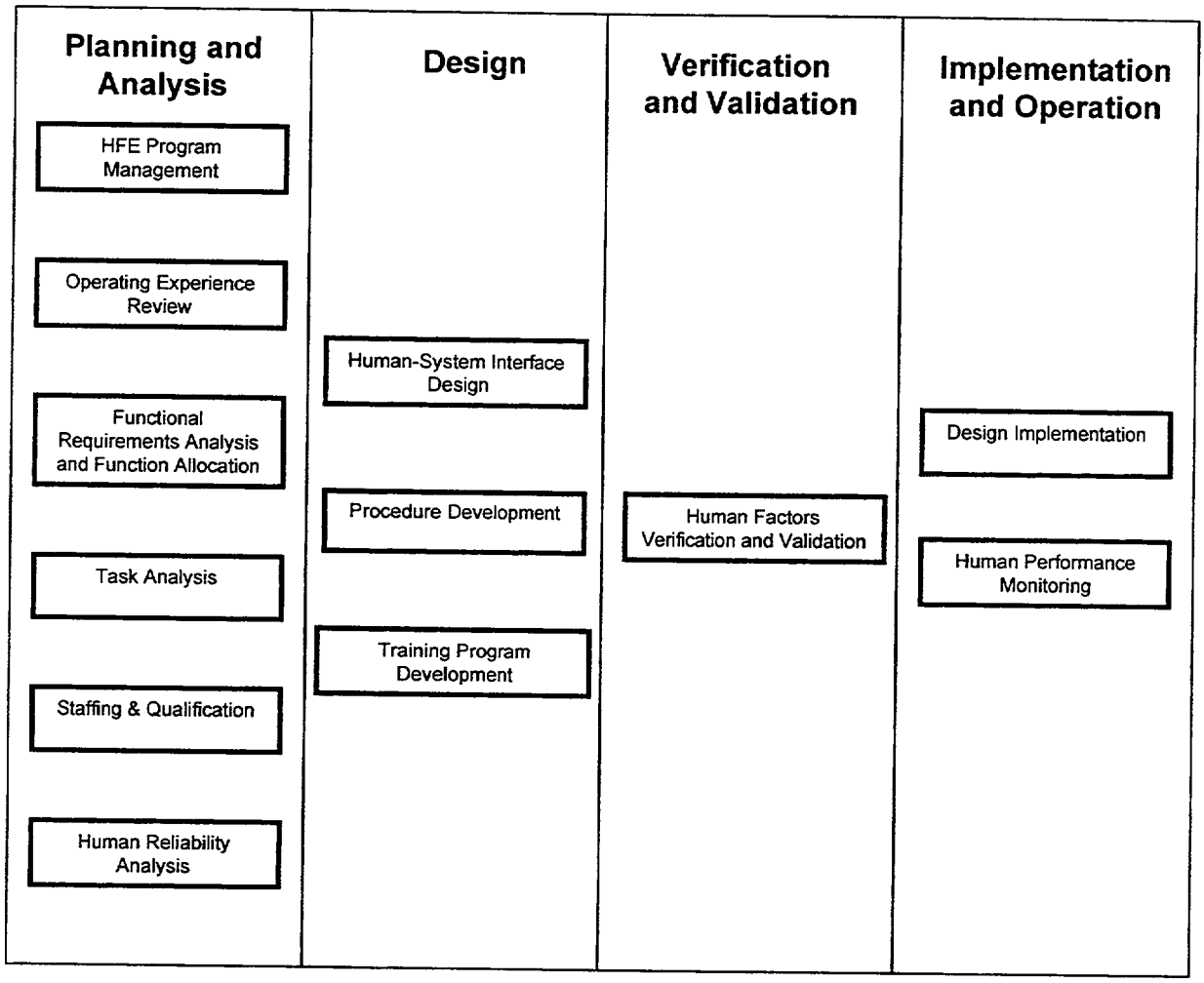

Figure 1.1 HFE Program Review Model Review Elements

an applicant may choose to provide this information in a single report. It is also possible that, for more complex elements such as HSI Design or V&V, more than two reports may be submitted in order to address all criteria. When additional information, is needed, it is identified in this section of each element. In addition to reports, the reviewer may review sample work products.

(4) *Review Criteria* - This section contains the acceptance criteria for design process products and for the final design review. Where appropriate, references to more detailed NRC guidance, e.g., NUREG-0700, are provided.

1.2.2 Sources of Additional Information

Applicants should conduct their activities relative to each element using accepted HFE practices as specified by applicable regulatory documents and codes, HFE standards, and guidelines. Therefore, for most elements, a list of documents that contain generally recognized acceptable approaches is provided. However, there are some qualifiers:

- References include documents that are periodically updated, such as NUREG-0700. The reference contained herein is to the latest version of the document available. One should consult the latest version of the document at the time of usage.
- Each individual document listed for a given element does not necessarily address all aspects of that element. In the conduct of a review of each element, a combination of the applicable sections of several of the identified documents may be appropriate.
- All of the documents referenced are not necessarily applicable to every design review.
- Where inconsistencies or contradictions within and between documents exist, they should be resolved and justified on a case-by-case basis.
- It should not be inferred that the listed documents provide complete guidance for each and every activity encompassed by the element. HFE is still an evolving discipline; therefore, not all HFE activities are adequately covered in codes, standards, and guidelines.
- Alternative approaches to those described in the referenced documents may be acceptable if they have defensible rationales. The NRC will evaluate alternative approaches proposed by applicants on a case-by-case basis.

1.3 Applications

The review methodology presented in this document addresses the scope of NRC HFE reviews identified in NUREG-0800 and can be used to review applications for construction permits, operating licenses, standard design certifications, and combined operating licenses. This document can also be used to review changes or modifications to licenses for nuclear power plants that include changes to human actions, e.g., a license amendment request. The NRC, the nuclear industry, and the public, have moved to a broader consideration of risk in many activities associated with NPPs. Therefore, risk importance should be taken into account when deciding which particular items to review and the depth of reviews to be undertaken. The purpose of these HFE reviews is to ensure safety by verifying that accepted human factors engineering practices and guidelines are incorporated into the plant and program designs.

1.3.1 Application to Current Applicants Under 10 CFR Part 50

This document can be used by the NRC staff in the following circumstances:

Review of the HFE Aspects of a New Plant

If an applicant proposes to build a new plant under 10 CFR Part 50 requirements, an HFE review would be performed in accordance with NUREG-0800. NUREG-0800 describes the staff's review activities to verify that accepted human factors engineering principles are incorporated during the design process and that the HFE reflects a state-of-the-art HFE design. NUREG-0800 provides a reference to NUREG-0711 for detailed review.

Voluntary Modifications to Plants Affecting Personnel Performance

The NRC staff would use the guidance in this document to ensure that voluntary modifications are acceptable. NUREG-0711 also contains risk considerations, which consider risk-informed evaluations and regulation. The term modification is used generically to include any type of change or modernization made to plant systems, HSIs, procedures, or training that may influence personnel performance. For

example, when computer-based HSI technology is integrated into existing control rooms, hybrid HSIs are created; i.e., HSIs containing a mixture of conventional and advanced technology. An HFE review should be conducted if the modification affects the role of personnel or the tasks they perform and is potentially significant to plant safety. Modifications affect the role or tasks of personnel if they impose new or different demands on them to operate, maintain, or otherwise ensure safety.

A modification may be considered potentially significant to plant safety, if it is identified in 10 CFR 50.59(c)(2). In addition, the staff may use this document when evaluating changes to the plant under 10 CFR 50.59 that are related to the HSI and personnel performance.

Additional guidance related to 10 CFR 50.59 is provided in RG 1.187 (NRC, 2000) and Nuclear Energy Institute (NEI) publication 96-07, entitled *Guidelines for 10 CFR 50.59 Implementation,* (NEI, 2000). The following sections from NEI 96-07 identify plant modifications for which NUREGs-0711 and -0700 would be used:

- In Section 4.3.2, *Does the Activity Result in More Than a Minimal Increase in the Likelihood of Occurrence of a Malfunction of an SSC (Structures, Systems, and Components) Important to Safety*, examples are provided of cases that would require prior NRC approval. Example 7 states that, "The change would (permanently) substitute manual action for automatic actions for performing UFSAR-described design functions" (p. 48).
- Section 4.3.6, *Does the Activity Create a Possibility for a Malfunction of an SSC Important to Safety with a Different Result*, indicates that, "An example of a change that would create the possibility for a malfunction with a different result is a substantial modification to control station alarms, controls, or displays that are associated with SSCs important to safety that creates a new or common cause failure that is not bounded by previous analyses or evaluations" (p. 55).

Staff Investigation of Events Involving Human Performance

NRC inspectors would use selected elements of the guidance in this document to support the review of those aspects of incidents that have important human performance contributions.

1.3.2 Application to Advanced NPP Applicants Under 10 CFR Part 52

NPP designers and vendors submit designs of advanced standardized NPPs to the NRC for review and approval under 10 CFR Part 52, *Early Site Permits: Standard Design Certifications and Combined Licenses for Nuclear Power Plants,* (see Subpart B, Standard Design Certification). To obtain a standard design certification under Part 52, applicants submit a standard safety analysis report (SSAR) which should include information on the HFE program. However, since technology is continually advancing, details of the applicant's HFE design might not be complete before a design certification is issued by NRC. In such cases, reviews under 10 CFR Part 52 would primarily focus on the design process. The extent of design documentation and technology reviewed at the design certification stage has varied among different NPP designs.

Applicants seeking to operate a standardized NPP under 10 CFR Part 52 who already received a design certification obtain a Combined Operating License (COL). In cases where portions of the design were not complete at the time of design certification, the detailed design review then would occur at the COL stage. Thus, for advanced NPPs, reviews using this document can occur at different points within the 10 CFR Part 52 application and licensing process and can include reviews of the following items:

- design documentation, such as design-specific HFE guidance documents and specifications
- prototype designs
- completed designs
- HFE related inspections, tests, analyses, and acceptance criteria (ITAAC) (to ensure that an as-built plant conforms to the standard design certification)
- HFE related design acceptance criteria (DAC) (to ensure that the applicant properly executes the design process after certification)

In addition, once an advanced reactor is operated under an NRC license, the staff can use the guidance in this document, as per the SRP's reference to this document for detailed review guidance, to support reviews of voluntary modifications to the advanced reactor, and to support investigations of events involving human performance, as discussed in Section 1.3 above.

For reviews associated with advanced reactors (10 CFR Part 52), the methodology does not define which elements have to be completed for design certification and which may be deferred until post certification. The applicant indicates which aspects of each element have been completed and, therefore, reviewed under NRC design certification evaluations. All criteria are met before plant startup.

1.4 Graded Approach to Review

The guidance in NUREG-0800 indicates that, "For any given application, the staff reviewers may select and emphasize particular aspects of each SRP section as is appropriate for the application... the staff may not carry out in detail all of the review steps listed in each SRP section in the review of every application" (p. 3). Thus the level of staff review of an applicant's HFE design should reflect the unique circumstances of the review. In Chapter 18, this type of tailoring of the review is identified:

> Judgement regarding areas of review to be given attention for an applicant's submittal should be based on evaluation of the information provided by the applicant, the similarity of the associated HFE issues to those recently reviewed for other plants, and the determination of whether items of special or unique safety significance are involved. Also, the relevance of each area of review and the appropriate level of detail of evidence should be considered with respect to such factors as the purpose of the review, the nature of the HFE concern, the status of the applicant's design process, the scope of the design, and the goal of the review (e.g., design certification, licensing) (p. 18.0.2).

The review methodology presented in this document is discussed generically. Therefore, the guidance should be selectively applied to address the demands of each specific review. In its complete form, the review process provides a comprehensive, detailed evaluation. This approach should be used for the review of a new plant design or an extensive control room modernization. Under certain circumstances, such as a preliminary review of an applicant's design prototype, or a focused review of one aspect of the design that might be implicated in an incident involving human performance, the focus of the staffs'

review will be more limited. In that case, the reviewer should select the relevant criteria to meet the demands of the review.

2 HFE PROGRAM MANAGEMENT

2.1 Background

The overall purpose of the HFE program review is to ensure that:

- The applicant has integrated HFE into plant development, design, and evaluation.
- The applicant has provided HFE products (e.g., HSIs, procedures, and training) that allow safe, efficient, and reliable performance of operation, maintenance, test, inspection, and surveillance tasks.
- The HFE program and its products reflect "state-of-the-art human factors principles" [10 CFR 50.34(f)(2)(iii)) as required by 10 CFR 52.47(a)(1)(ii)] and satisfies all specific regulatory requirements.

10 CFR 52.47 requires that applications for design certification of new reactor designs meet the technically relevant portions of the TMI requirements contained in 10 CFR 50.34(f). Pertinent to this document, 50.34 requires a control room design that reflects state-of-the-art human factors principles. As further examples, 50.34 also requires: an SPDS console, automatic indication of bypassed and inoperable status of safety systems, full scope simulator capability, and monitoring capability in the control room of a variety of system parameters.

State-of-the-art human factors principles are defined as those principles currently accepted by human factors practitioners. "Current" is defined with reference to the time when a program management or implementation plan is prepared. "Accepted" is defined as a practice, method, or guide that is (1) documented in the human factors literature within a standard or guidance document that has undergone a peer-review process or (2) can be justified through scientific research and/or industry practices.

To accomplish these purposes, an applicant should have an HFE program plan which is implemented by a qualified HFE design team. The term "HFE design team" generically refers to the primary organization or function within the organization that is responsible for HFE within the scope of the staff's review. There is, however, no assumption that HFE is the responsibility of a single organization or that there is an organizational unit called the HFE design team.

2.2 Objective

The objective of this review element is to ensure that the applicant has an HFE design team with the responsibility, authority, placement within the organization, and composition to ensure that the design commitment to HFE is met. Also, the team should be guided by a plan to ensure that the HFE program is properly developed, executed, overseen, and documented. This plan should describe the technical program elements ensuring that all aspects of the HSI, procedures, and training are developed, designed, and evaluated on the basis of a structured top-down systems analysis using accepted HFE principles. In addition, the HFE program as a whole should appropriately consider and address the deterministic aspects of design, as discussed in RG 1.174.

2.3 Applicant Submittals

The applicant should provide the following for staff review: HFE program plan describing the applicant's HFE goals/objectives, technical program to accomplish the objectives, a system to track HFE issues, the HFE design team, and the management and organizational structure to allow the technical program to be accomplished.

2.4 Review Criteria

HFE Program Management review topics include:

- general HFE program goals and scope
- HFE team and organization
- HFE process and procedures
- HFE issues tracking
- technical program

2.4.1 General HFE Program Goals and Scope

(1) *HFE Program Goals* - The general objectives of the program should be stated in "human-centered" terms, which, as the HFE program develops, should be defined and used as a basis for HFE test and evaluation activities. Generic "human-centered" HFE design goals include the following:

- personnel tasks can be accomplished within time and performance criteria
- the HSIs, procedures, staffing/qualifications, training and management and organizational support will support a high degree of operating crew situation awareness
- the plant design and allocation of functions will maintain operation vigilance and provide acceptable workload levels i.e., to minimize periods of operator underload and overload
- the operator interfaces will minimize operator error and will provide for error detection and recovery capability

(2) *Assumptions and Constraints* - An assumption or constraint is an aspect of the design, such as a specific staffing plan or the use of specific HSI technology, that is an *input* to the HFE program rather than the result of HFE analyses and evaluations. The design assumptions and constraints should be clearly identified.

(3) *Applicable Facilities* - The HFE program should address the main control room, remote shutdown facility, technical support center (TSC), emergency operations facility (EOF), and local control stations (LCSs).

(4) *Applicable HSIs, Procedures and Training* - The applicable HSIs, procedures, and training included in the HFE program should include all operations, accident management, maintenance, test, inspection and surveillance interfaces (including procedures).

(5) *Applicable Plant Personnel* - Plant personnel who should be addressed by the HFE program include licensed control room operators as defined in 10 CFR Part 55 and the following categories of personnel defined by 10 CFR 50.120: nonlicensed operators, shift supervisor, shift technical advisor, instrument and control technician, electrical maintenance personnel, mechanical maintenance personnel, radiological protection technician, chemistry technician, and engineering support personnel. In addition, any other plant personnel who perform tasks that are directly related to plant safety should be addressed.

For plant modifications, the HFE program should include the involvement of plant personnel to ensure that the following are considered from a user's perspective in establishing modification requirements and evaluating the design process's outputs:

- user's understanding of how plant systems are structured and behave
- task demands and constraints of the existing work environment
- existing work processes
- organizational goals that affect the implementation and use of the modification

(6) *Effects of Modifications on Personnel Performance* - The goals of the HFE program should address the need to consider the effects that the modification may have on the performance of personnel. The transition from the existing plant configuration to the modification configuration can pose demands on human performance that differ from either the initial or final configurations. Therefore, it should be planned so it places minimal demands for adapting to the change. The considerations should include the following:

- planning the installation to minimize disruptions to work
- coordinating training and procedure modifications with implementing the modification to ensure that both accurately reflect its characteristics.
- conducting training to maximize personnel's knowledge and skill with the new design before its implementation

2.4.2 HFE Team and Organization

(1) *Responsibility* - The team should be responsible (with respect to the scope of the HFE program) for (a) the development of all HFE plans and procedures; (b) the oversight and review of all HFE design, development, test, and evaluation activities; (c) the initiation, recommendation, and provision of solutions through designated channels for problems identified in the implementation of the HFE activities; (d) verification of implementation of team recommendations; (e) assurance that all HFE activities comply with the HFE plans and procedures; and (f) scheduling of activities and milestones.

(2) *Organizational Placement and Authority* - The primary HFE organization(s) or function(s) within the organization of the total program should be identified, described, and illustrated (e.g., charts to show organizational and functional relationships, reporting relationships, and lines of communication). When more than one organization is responsible for HFE, the lead organizational unit responsible for the HFE program plan should be identified. The team should have the authority and organizational placement to ensure that all its areas of responsibility are accomplished and to identify problems in the implementation of the overall plant design. The

team should have the authority to control further processing, delivery, installation, or use of HFE products until the disposition of a nonconformance, deficiency, or unsatisfactory condition has been achieved.

(3) *Composition* - The HFE design team should include the expertise described in the Appendix.

(4) *Team Staffing* - Team staffing should be described in terms of job descriptions and assignments of team personnel.

2.4.3 HFE Process and Procedures

(1) *General Process Procedures* - The process through which the team will execute its responsibilities should be identified. The process should include procedures for:

- assigning HFE activities to individual team members
- governing the internal management of the team
- making management decisions regarding HFE
- making HFE design decisions
- governing equipment design changes
- design team review of HFE products

(2) *Process Management Tools* - Tools and techniques (e.g., review forms) to be utilized by the team to ensure they fulfill their responsibilities should be identified.

(3) *Integration of HFE and Other Plant Design Activities* - The integration of design activities should be identified, that is, the inputs from other plant design activities to the HFE program and the outputs from the HFE program to other plant design activities. The iterative nature of the HFE design process should be addressed.

(4) *HFE Program Milestones* - HFE milestones should be identified so that evaluations of the effectiveness of the HFE effort can be made at critical check points and the relationship to the integrated plant sequence of events is shown. A relative program schedule of HFE tasks showing relationships between HFE elements and activities, products, and reviews should be available for review.

(5) *HFE Documentation* - HFE documentation items should be identified and briefly described along with the procedures for retention and access.

(6) *Subcontractor HFE Efforts* - HFE requirements should be included in each subcontract and the subcontractor's compliance with HFE requirements should be periodically verified.

2.4.4 HFE Issues Tracking

(1) *Availability* - A tracking system should be available to address human factors issues that are (a) known to the industry (defined in the Operating Experience Review element, see Section 3) and (b) identified throughout the life cycle of the HFE aspects of design, development, and evaluation. Issues are those items that need to be addressed at some later date and thus need to be tracked to ensure that they are not overlooked. It is not necessary to establish a new system to

track HFE issues that is independent from the rest of the design effort. An existing tracking system may be adapted to serve this purpose (such as a plant's corrective action program, CAP).

(2) *Method* - The method should document and track HFE issues from identification until the potential for negative effects on human performance has been reduced to an acceptable level.

(3) *Documentation* - Each issue or concern that meets or exceeds the threshold established by the design team should be entered into the system when first identified, and each action taken to eliminate or reduce the issue or concern should be thoroughly documented. The final resolution of the issue should be documented in detail, along with information regarding design team acceptance.

(4) *Responsibility* - When an issue is identified, the tracking procedures should describe individual responsibilities for issue logging, tracking and resolution, and resolution acceptance.

2.4.5 Technical Program

(1) The general development of implementation plans, analyses, and evaluation of the following should be identified and described:

- operating experience review
- functional requirements analysis and function allocation
- task analysis
- staffing and qualifications
- human reliability analysis
- HSI design
- procedure design
- training design
- human factors verification and validation
- design implementation
- human performance monitoring

(2) The HFE requirements imposed on the design process should be identified and described. The standards and specifications that are sources of HFE requirements should be listed.

(3) HFE facilities, equipment, tools, and techniques (such as laboratories, simulators, rapid prototyping software) to be utilized in the HFE program should be specified.

(4) In accordance with RG 1.174, the applicant should provide assurance in the HFE plan that a plant modification meets current regulations, except where specific exemptions are requested under 10 CFR 50.12 or 10 CFR 2.802. For example, a modification might be identified as risk significant when using a standard probabilistic risk assessment (PRA) to screen for risk. However, an exemption might be granted under one or more of the following regulations: 10 CFR 20, 10 CFR 50 Appendix A, Criterion 19, and 10 CFR 50 Appendices C through R.

(5) The applicant should provide assurance in the HFE plan that a modification does not compromise defense-in-depth. Defense-in-depth is one of the fundamental principles upon which the plant was designed and built. Defense-in-depth uses multiple means to accomplish safety functions and to prevent the release of radioactive materials. Defense-in-depth is important in accounting for uncertainties in equipment and human performance, and for ensuring some protection remains even in the face of significant breakdowns in particular areas. Defense-in-depth may be changed but should be maintained overall. Important aspects of defense-in-depth are identified in RG 1.174, and include:

- A reasonable balance is preserved among prevention of core damage, prevention of containment failure, and consequence mitigation.
- There is no over-reliance on programmatic activities to compensate for weaknesses in plant design. This may be pertinent to changes in credited human actions (HAs).
- System redundancy, independence, and diversity are preserved commensurate with the expected frequency, consequences of challenges to the system, and uncertainties (e.g., no risk outliers).
- Defenses against potential common cause failures are preserved, and the potential for the introduction of new common cause failure mechanisms is assessed. Caution should be exercised in crediting new HAs to assure that the possibility of significant common cause errors is not created.
- Independence of barriers is not degraded.
- Defenses against human errors are preserved. For example, establish procedures for a second check or independent verification for risk-important HAs to determine that they have been performed correctly.
- The intent of the General Design Criteria (GDC) in Appendix A to 10 CFR Part 50 is maintained. GDC that may be relevant are 3 - Fire Protection, 13 - Instrumentation and Control, 17 - Electric Power Systems, 19 - Control Room, 34 - Residual Heat Removal, 35 - emergency core cooling system, 38 - Containment Heat Removal, and 44 - Cooling Water.
- Safety margins often used in deterministic analyses to account for uncertainty and provide an added margin to provide adequate assurance that the various limits or criteria important to safety are not violated. Such safety margins are typically not related toHAs, but the reviewer should take note to see if there are any that may apply to the particular case under review. It is also possible to add a safety margin (if desired) to the HA by demonstrating that the action can be performed within some time interval (or margin) that is less than the time identified by the analysis.

2.5 Sources of Additional Information

The following documents may be used for additional information (per Section 1.2.2):

IEC 964: *Design for Control Rooms of Nuclear Power Plants* (International Electrochemical Commission, 1989).

IEEE Std. 1023-1988: *IEEE Guide to the Application of Human Factors Engineering to Systems, Equipment, and Facilities of Nuclear Power Generating Stations* (Institute of Electrical and Electronics Engineers, 1988).

ISO 11064-1: *Ergonomic Design of Control Centres -- Part 1: Principles for the Design of Control Centres* (International Standards Organization, 2000).

Regulatory Guide 1.174: *An approach for using probabilistic risk assessment in risk-informed decisions on plant-specific changes to the licensing basis* (NRC, 1998).

U.S. Code of Federal Regulations, Part 55, "Operator's Licenses," Title 10, "Energy."

3 OPERATING EXPERIENCE REVIEW

3.1 Background

Applicant's should provide administrative procedures of evaluating operating, design and construction experience and for ensuring that applicable important industry experiences will be provided in a timely manner to those designing and construction the plant [10 CFR 50.34(f)(3)(i)]. The main purpose of conducting an operating experience review (OER) as part of the HFE review is to identify HFE-related safety issues. The OER should provide information on the past performance of predecessor designs. In the case of new plants this may be earlier designs on which the new design is based. In the case of plant modifications, it may be the design of the systems being changed. The issues and lessons learned from operating experience provide a basis for improving the plant design in a timely way; i.e., at the beginning of the design process.

The resolution of OER issues may involve function allocation, changes in automation, HSI equipment design, procedures, training, and so forth. Thus, negative features encountered in previous designs can be identified and analyzed so that they are avoided in the development of the current system and positive features can be retained.

OER information contributes to other review elements. These inputs are summarized in Table 3.1. As indicated in the table, OER can contribute to review and evaluation considerations as well as system design considerations. For example, OER can be used in the selection of specific failure scenarios to incorporate in validation testing and can be used as a basis to select specific performance measures for the evaluation (e.g., to measure an aspect of human performance identified in OER as being problematic).

Table 3.1 The Role of Operating Experience Review in the HFE Program

HFE ELEMENT	OER CONTRIBUTION
Functional Requirements Analysis and Function Allocation	• Basis for initial requirements • Basis for initial allocations • Identification of need for modifications
Task Analysis, Human Reliability Analysis, and Staffing/Qualifications	• Risk-important human actions and errors • Problematic operations and tasks • Staffing shortfalls
Human-System Interface, Procedures, and Training Development	• Trade study evaluations • Potential design solutions • Potential design issues
Human Factors Verification and Validation	• Tasks to be evaluated • Event and scenario selection • Performance measure selection • Issue resolution verification

3.2 Objective

The objective of reviewing operating experience is to assure that the applicant has identified and analyzed HFE-related problems and issues in previous designs that are similar to the current design under review. In this way, negative features associated with predecessor designs may be avoided in the current one while retaining positive features.

3.3 Applicant Submittals

As per Section 1.2.1, item (3) Applicant Submittals, the applicant should provide for staff review an *implementation plan* for conducting a review of operating experience. Upon completion of the applicant's OER, a *results summary report* should be submitted so that the staff can review the identification and analysis of HFE-related problems and issues using the criteria provided in Section 3.4 below. In addition, the reviewer may also audit the issue tracking system for examination of OER issue treatment.

3.4 Review Criteria

3.4.1 Scope

(1) *Predecessor/Related Plants and Systems* - The review should include information pertaining to the human factors issues related to the predecessor plant(s) or highly similar plants and plant systems. For a review of plant modifications, the scope of the OER should be focused to provide information relevant to the plants' systems, HSIs, procedures, or training that are being modified. It should address the operating experience of the plant that will be modified, including experiences with the systems that will be modified and with technologies that are similar to those under consideration for it. Some useful information may be found in the plant's CAP. Also, when personnel are unfamiliar with the proposed technology, attention should be paid to the operating experience of other plants that already have the technology.

(2) *Recognized Industry HFE Issues* - NUREG/CR-6400 (Higgins and Nasta, 1996) issues should be addressed. The issues are organized into the following categories:

- unresolved safety issues/generic safety issues
- TMI issues
- NRC generic letters and information notices
- reports of the former NRC Office for Analysis and Evaluation of Operational Data
- low power and shutdown operations
- operating plant event reports

(3) *Related HFE Technology* - The OER should address related HFE technology. For example, if touch screen interfaces or computerized procedures are planned, HFE issues associated with their use should be reviewed.

(4) *Issues Identified by Plant Personnel* - Personnel interviews should be conducted to determine operating experience related to predecessor plants or systems. The following topics should be included in the interviews as a minimum:

- Plant Operations
  - normal plant evolutions (e.g., startup, full power, and shutdown)

- instrument failures [e.g., safety-related system logic and control unit, fault tolerant controller (nuclear steam supply system), local "field unit" for multiplexer (MUX) system, MUX controller (balance of plant), break in MUX line]
- HSI equipment and processing failure (e.g., loss of video display units, loss of data processing, loss of large overview display)
- transients (e.g., turbine trip, loss of offsite power, station blackout, loss of all feedwater, loss of service water, loss of power to selected buses or CR power supplies, and safety/relief valve transients)
- accidents (e.g., main steam line break, positive reactivity addition, control rod insertion at power, control rod ejection, anticipated transients without scram (ATWS), and various-sized loss-of-coolant accidents (LOCA))
- reactor shutdown and cooldown using remote shutdown system

• HFE Design Topics

- alarm and annunciation
- display
- control and automation
- information processing and job aids
- real-time communications with plant personnel and other organizations
- procedures, training, staffing/qualifications, and job design

(5) *Risk-Important Human Actions* - The OER should identify risk-important HAs that have been identified as different or where errors have occurred. The human actions should be identified as requiring special attention during the design process to lessen their probability.

3.4.2 Issue Analysis, Tracking, and Review

(1) *Analysis Content* - The issues should be analyzed with regard to the identification of

• human performance issues, problems, and sources of human error
• design elements that support and enhance human performance

(2) *Documentation* - The analysis of operating experience should be documented in an evaluation report.

(3) *Incorporation Into the Tracking System* - Each operating experience issue determined to be appropriate for incorporation in the design (but not already addressed in the design) should be documented in the issue tracking system.

3.5 Sources of Additional Information

The following documents may be used for additional information (per Section 1.2.2):

IAEA Safety Series No. 75-INSAG-3: *Basic Safety Principles for Nuclear Power Plants* (International Atomic Energy Agency (1988).

IEEE Std. 1023-1988: *IEEE Guide to the Application of Human Factors Engineering to Systems, Equipment, and Facilities of Nuclear Power Generating Stations* (Institute of Electrical and Electronics Engineers, 1988).

IEEE Std. 845-1999: *IEEE Guide to the Evaluation of Human-System Performance in Nuclear Power Generating Stations* (Institute of Electrical and Electronics Engineers, 1999).

NUREG/CR-6400: *HFE Insights For Advanced Reactors Based Upon Operating Experience* (Higgins and Nasta, 1996).

4 FUNCTIONAL REQUIREMENTS ANALYSIS AND FUNCTION ALLOCATION

4.1 Background

Functional requirements analysis is the identification of functions that must be performed to satisfy plant safety objectives; that is, to prevent or mitigate the consequences of postulated accidents that could damage the plant or cause undue risk to the health and safety of the public. A functional requirements analysis is conducted to (1) determine the objectives, performance requirements, and constraints of the design, (2) define the high-level functions that have to be accomplished to meet the objectives and desired performance, (3) define the relationships between high-level functions and plant systems (e.g., plant configurations or success paths) responsible for performing the function, and (4) provide a framework for understanding the role of controllers (whether personnel or system) for controlling the plant.

Function allocation is the analysis of the requirements for plant control and the assignment of control functions to (1) personnel (e.g., manual control), (2) system elements (e.g., automatic control and passive, self-controlling phenomena), and (3) combinations of personnel and system elements (e.g., shared control and automatic systems with manual backup). Plant safety and reliability are enhanced by exploiting the strengths of personnel and system elements, including improvements that can be achieved through the assignment of control to these elements with overlapping and redundant responsibilities. In addition to technological and economic considerations, function allocation should be based on HFE principles using a structured and well-documented methodology that seeks to provide personnel with logical, coherent, and meaningful tasks. It should not be based solely on technology considerations that allocate to plant personnel everything the designers cannot automate. Such an approach results in an ad hoc set of activities that may negatively affect operator performance.

The purpose of the functional requirements analysis and function allocation review is to ensure that the plant's safety functions have been defined and that the allocation of those functions to human and system resources has resulted in a role for personnel that takes advantage of human strengths and avoids human limitations.

Functional requirements analysis is not only a consideration for new designs. Plant modifications can change the level of automation of the original design; e.g., full-range feedwater control systems, which in turn effects the roles and responsibilities of plant personnel.

4.2 Objective

The objective of the functional requirements analysis and functional allocation review is to ensure that the applicant has (1) defined the plant's functions that must be performed to satisfy plant safety objectives, and (2) that the allocation of those functions to human and system resources has resulted in a role for personnel that takes advantage of human strengths and avoids human limitations.

4.3 Applicant Submittals

As per Section 1.2.1, item (3) Applicant Submittals, the applicant should provide for staff review an *implementation plan* for conducting functional requirements analysis and functional allocation. Upon completion of the applicant's efforts, a *results summary report* should be submitted so that the staff can review the applicant's definition of the plant's functions and the allocation of functions to human and system resources using the criteria provided in Section 4.4 below.

4.4 Review Criteria

(1) Functional requirements analysis and function allocation should be performed using a structured, documented methodology reflecting HFE principles. An example functional allocation process and considerations is shown in Figure 4.1. The functional requirements analysis and function allocation may be graded based on:

- the degree to which the functions of the new design differ from those of the predecessor
- the extent to which difficulties related to plant functions were identified in the plant's operating experience and will be addressed in the new design.

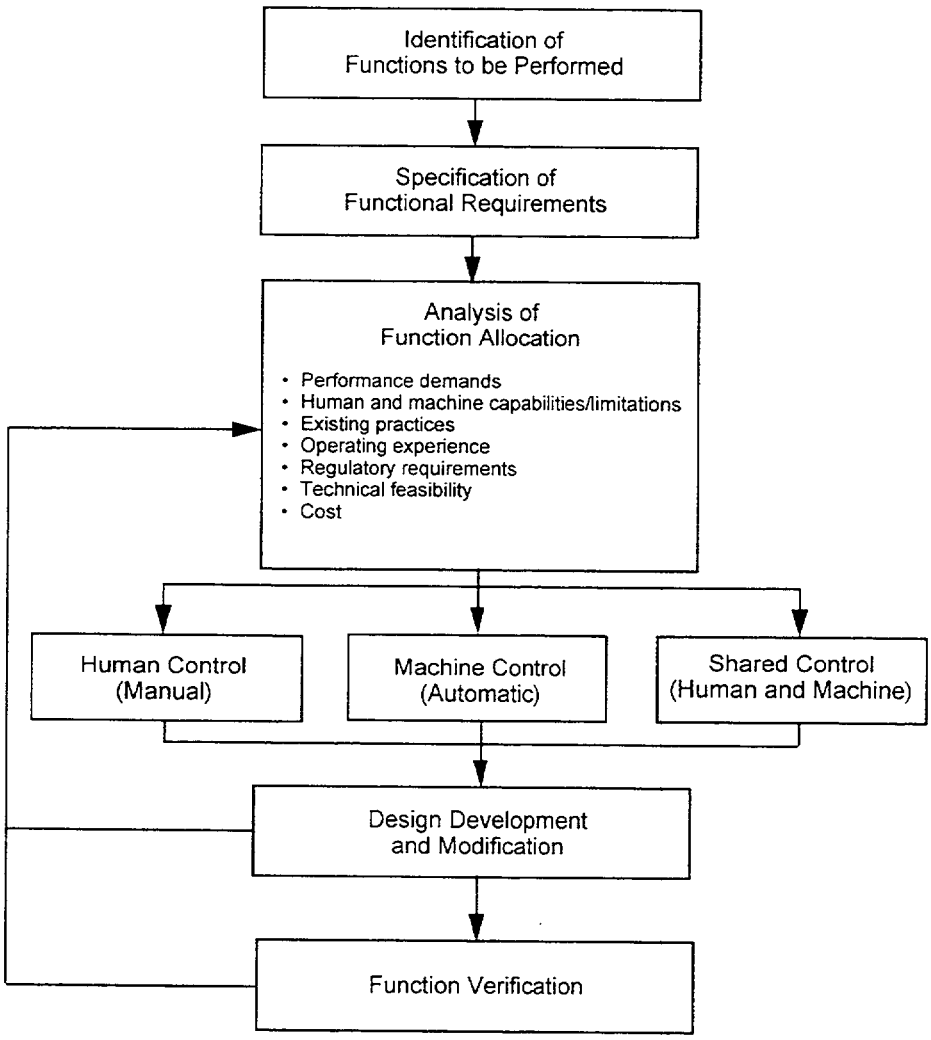

Fig 4.1 Allocation of Functions to Human and Machine Resources

(2) The functional requirements analysis and function allocation should be kept current over the life cycle of design development and held until decommissioning so that it can be used as a design basis when modifications are considered. Control functions should be re-allocated in an iterative manner, in response to developing design specifics, operating experience, and the outcomes of ongoing analyses and trade studies.

(3) A description of the functions and systems should be provided along with a comparison to the reference plants/systems, i.e., the previous plants or plant systems on which the new system is based. This description should identify differences that exist between the proposed and reference plants/systems. Safety functions (e.g., reactivity control) include functions needed to prevent or mitigate the consequences of postulated accidents that could cause undue risk to the health and safety of the public. For each safety function, the set of plant system configurations or success paths that are responsible for or capable of carrying out the function should be clearly defined. Function decomposition should start at "top-level" functions where a very general picture of major functions is described, and continue to lower levels until a specific critical end-item requirement emerges (e.g., a piece of equipment, software, or HA). The functional decomposition should address the following levels

- high-level functions [e.g., maintain reactor coolant system (RCS) integrity] and critical safety functions (e.g., maintain RCS pressure control)
- specific plant systems and components

(4) A description should be provided for each high-level function which includes:

- purpose of the high-level function
- conditions that indicate that the high-level function is needed
- parameters that indicate that the high-level function is available
- parameters that indicate the high-level function is operating (e.g., flow indication)
- parameters that indicate the high-level function is achieving its purpose (e.g., reactor vessel level returning to normal)
- parameters that indicate that operation of the high-level function can or should be terminated

Note that parameters may be described qualitatively (e.g., high or low). Specific data values or setpoints are not necessary at this stage.

(5) The technical basis for modifications to high-level functions in the new design (compared to the predecessor design) should be documented.

(6) The technical basis for all function allocations should be documented; including the allocation criteria, rationale, and analyses method. The technical basis for functional allocation can be any one or combination of the evaluation factors (see Fig 4.1). For example, the performance demands to successfully achieve the function, such as degree of sensitivity needed, precision, time, or frequency of response, may be so stringent that it would be difficult or error prone for personnel to accomplish. This would establish a basis for automation (assuming acceptability of other factors, such as technical feasibility or cost).

(7) The OER should be used to identify modifications to function allocations, if necessary. If problematic OER issues are identified, then an analysis should be performed to (a) justify the original analysis of the function, (b) justify the original human-machine allocation, and

(c) identify solutions such as training, personnel selection, and procedure design that will be implemented to address the OER issues.

(8) The allocation analysis should consider not only the primary allocations to personnel, but also their responsibilities to monitor automatic functions and to assume manual control in the event of an automatic system failure.

(9) A description of the integrated personnel role across functions and systems should be provided in terms of personnel responsibility and level of automation.

(10) The functional requirements analysis and function allocation should be verified:

- all the high-level functions necessary for the achievement of safe operation are identified.
- all requirements of each high-level function are identified.
- the allocations of functions result in a coherent role for plant personnel

(11) When the analyses address plant modifications, the following considerations should also be addressed:

- Functional requirements analyses for modifications that are likely to change existing safety functions, introduce new functions for systems supporting safety functions, or involve unclear functional requirements that may be important to safety. The functional requirements analysis should address new functions resulting from changes in the degree of integration between plant systems. For example, installing higher-level automation may bring systems that were formerly controlled separately under a single controller. Also, the modifications may change the degree to which different plant systems share common resources (e.g., power sources, cooling water, and data-transmission buses). These may be important in diagnosing malfunctions or planning responses. The functional requirements analyses should be revised and updated to reflect requirements of the modification; the scope of the analyses may be restricted to functions related to the modification.
- Function allocation analyses for modifications that are likely to change the allocation between personnel and plant systems of functions important to safety. The analyses should be revised and updated to reflect requirements for the modification; their scope may be restricted to functions involving the modification.
- A change in an operator's role due to a modification should be examined within the context of its effects on the operator's overall responsibilities. Increases in certain task demands may affect the ability of the operator to carry out others that are risk-important.

4.5 Sources of Additional Information

The following documents may be used for additional information (per Section 1.2.2):

HWR-639: *FAME - A Function Allocation Design Tool* (Bye and Hoffman, 2001).

IAEA-TECDOC-668: *The Role of Automation and Humans in Nuclear Power Plants* (International Atomic Energy Agency, 1992).

IEC 964: *Design for Control Rooms of Nuclear Power Plants* (International Electrochemical Commission, 1989).

NASA Technical Memo No. 103885: *Human-Centered Aircraft Automation: A Concept and Guidelines* (Billings, 1991).

NUREG/CR-2623: *The Allocation of Functions in Man-Machine Systems: A Perspective and Literature Review* (Price, et al., 1982).

NUREG/CR-3331: *A Methodology for Allocation of Nuclear Power Plant Control Functions to Human and Automated Control* (Pulliam et al., 1983).

5 TASK ANALYSIS

5.1 Background

The functions allocated to plant personnel define their roles and responsibilities. Human actions are performed to accomplish these functions. HAs can be further divided into tasks. A task is a group of related activities that have a common objective or goal. Task analysis is the identification of requirements for accomplishing these tasks, i.e., for specifying the requirements for the displays, data processing, controls, and job support aids needed to accomplish tasks. As such, the results of task analysis are identified as inputs in many HFE activities; e.g., it forms the basis for

- staffing, qualifications, job design, and training
- HSIs, procedures, and training program design
- task support verification criteria definition (see Human Factors Verification and Validation in Section 11).

5.2 Objective

The objective of this review is to ensure that the applicant's task analysis identifies the specific tasks that are needed for function accomplishment and their information, control and task-support requirements.

5.3 Applicant Submittals

As per Section 1.2.1, item (3) Applicant Submittals, the applicant should provide for staff review an *implementation plan* for conducting task analysis. Upon completion of the applicant's efforts, a *results summary report* should be submitted so that the staff can review the applicant's identification of tasks that are needed for function accomplishment and their information, control and task-support requirements using the criteria provided in Section 5.4 below.

5.4 Review Criteria

(1) The scope of the task analysis should include:

- selected representative and important tasks from the areas of operations, maintenance, test, inspection, and surveillance
- full range of plant operating modes, including startup, normal operations, abnormal and emergency operations, transient conditions, and low-power and shutdown conditions
- HAs that have been found to affect plant risk by means of PRA importance and sensitivity analyses should also be considered risk-important. Internal and external initiating events and actions affecting the PRA Level I and II analyses should be considered when identifying risk-important actions
- where critical functions are automated, the analyses should consider all human tasks including monitoring of the automated system and execution of backup actions if the system fails.

(2) Tasks should be linked using a technique such as operational sequence diagrams. Task analyses should begin on a gross level and involve the development of detailed narrative descriptions of what personnel have to do. The analyses should define the nature of the input, process, and output needed by and of personnel. Detailed task descriptions should address (as appropriate) the topics listed in Table 5.1

Table 5.1 Task Considerations

Type of Information	Example
Information Requirements	alarms and alerts parameters (units, precision, and accuracy) feedback needed to indicate adequacy of actions taken
Decisionmaking Requirements	decisions type (relative, absolute, probabilistic) evaluations to be performed
Response Requirements	type of action to be taken task frequency, tolerance and accuracy time available and temporal constraints (task ordering) physical position (stand, sit, squat, etc.) biomechanics - movements (lift, push, turn, pull, crank, etc.) - forces needed
Communication Requirements	personnel communication for monitoring information or control
Workload	cognitive physical overlap of task requirements (serial vs. parallel task elements)
Task Support Requirements	special and protective clothing job aids or reference materials needed tools and equipment needed
Workplace Factors	ingress and egress paths to the worksite workspace envelope needed by action taken typical and extreme environmental conditions, such as lighting, temp, noise
Situational and Performance Shaping Factors	stress reduced manning
Hazard Identification	identification of hazards involved, e.g., potential personal injury

(3) The task analysis should be iterative and become progressively more detailed over the design cycle. It should be detailed enough to identify information and control requirements to enable specification of detailed requirements for alarms, displays, data processing, and controls for human task accomplishment.

(4) The task analysis should address issues such as:

- the number of crew members
- crew member skills
- allocation of monitoring and control tasks to the (a) formation of a meaningful job and (b) management of crew member's physical and cognitive workload.

(5) The task analysis results should be used to define a minimum inventory of alarms, displays, and controls necessary to perform crew tasks based on both task and instrumentation and control requirements.

(6) The task analysis results should provide input to the design of HSIs, procedures, and personnel training programs.

(7) The following considerations should be addressed for plant modifications that are likely to affect HAs previously identified as risk-important, cause existing HAs to become risk-important, or create new actions that are risk-important.

- The tasks analyses should be revised and updated to reflect requirements of the modification; the scope should include tasks involving the modification and its interactions with the rest of the plant, including those resulting from functions addressed in the analyses of functional requirements and function allocation. For maintenance, tests, inspections, and surveillances, attention should be given to risk-important actions that are new or supported by new technologies (e.g., new capabilities for on-line maintenance).
- The task analysis should identify the design characteristics of the existing HSIs that support the performance of experienced personnel (e.g., support high levels of performance during demanding situations). They may include the spatial arrangement of control- and display-devices and the ability to adjust controls and displays to deal with special tasks. These design characteristics should be considered in developing new design requirements. That is, the new design should have features performing similar functions, or should eliminate the need for them by performing these functions differently. In addition, the task analysis should identify and examine adjustments made to the HSIs by users, such as notes and external memory-aids, which suggest that the users' needs may not be fully met by its current design. All task demands should be adequately addressed by the new design requirements. Design features identified during OERs should be considered in these analyses.

5.5 Sources of Additional Information

The following documents may be used for additional information (per Section 1.2.2):

A Guide to Task Analysis (Kirwan and Ainsworth, 1992).

Cognitive Task Analysis (Shraagen, Chipman, and Shalin, 2000).

Cognitive Work Analysis: Toward Safe, Productive, and Healthy Computer-Based Work (Vicente, 1999).

IEC 964: *Design for Control Rooms of Nuclear Power Plants* (International Electrotechnical Commission, 1989).

NUREG/CR-3371: *Task Analysis of Nuclear Power Plant Control Room Crews* (Burgy et al., 1983).

6 STAFFING AND QUALIFICATIONS

6.1 Background

Plant staff and their qualifications are important consideration throughout the design process. Initial staffing levels may be established based on experience with previous plants, staffing goals (such as for staffing reductions), initial analyses, and government regulations. However, the acceptability of the staffing goals and assumptions should be examined as the design of the plant proceeds.

6.2 Objective

The objective of the staffing review is to ensure that the applicant has systematically analyzed the requirements for the number and qualifications of personnel that includes a thorough understanding of task requirements and regulatory requirements.

6.3 Applicant Submittals

As per Section 1.2.1, item (3) Applicant Submittals, the applicant should provide for staff review an *implementation plan* for staffing and qualifications analysis. Upon completion of the applicant's efforts, a *results summary report* should be submitted so that the staff can review the applicant's evaluation of the requirements for the number and qualifications of personnel using the criteria provided in Section 6.4 below.

6.4 Review Criteria

(1) Staffing and qualifications should address applicable requirements of NUREG-0800 Section 13.1 and 10 CFR 50.54.

(2) The staffing analysis should determine the number and background of personnel for the full range of plant conditions and tasks including operational tasks (normal, abnormal, and emergency), plant maintenance, and plant surveillance and testing. The scope of personnel that should be considered is identified in the HFE Program Management element (see Section 2.4.1, Criterion 5).

(3) The staffing analysis should be iterative; that is, initial staffing goals should be reviewed and modified as the analyses associated with other elements are completed.

(4) The basis for staffing and qualifications should be modified to address these issues:

- Operating Experience Review
  - operational problems and strengths that resulted from staffing levels in predecessor systems
  - initial staffing goals and their bases including staffing levels of predecessor systems and a description of significant similarities and differences between predecessor and current systems
  - staffing considerations described in NRC Information Notice 95-48, "Results of Shift Staffing Study"
  - staffing considerations described in NRC Information Notice 97-78, "Crediting of Operator Actions in Place of Automatic Actions and Modifications of Operator Actions, Including Response Times"

- Functional Requirements Analysis and Function Allocation

- mismatches between functions allocated to personnel and their qualifications
- changes the roles of personnel due to plant system and HFE modifications

- Task Analysis
  - the knowledge, skills, and abilities needed for personnel tasks addressed by the task analysis
  - personnel response time and workload
  - personnel communication and coordination, including interactions between them for diagnosis, planning, and control activities, and interactions between personnel for administrative, communications, and reporting activities
  - the job requirements that result from the sum of all tasks allocated to each individual both inside and outside the control room
  - decreases in the ability of personnel to coordinate their work due to plant and HFE modifications
  - availability of personnel considering other activities that may be ongoing and for which operators may take on responsibilities outside the control room (e.g., fire brigade)
  - actions identified in 10 CFR 50.47, NUREG-0654, and procedures to meet an initial accident response in key functional areas as identified in the emergency plan
  - staffing considerations described by the application of ANSI/ANS 58.8-1994, "Time Response Design Criteria for Safety-Related Operator Actions"

- Human Reliability Analysis
  - the effect of overall staffing levels on plant safety and reliability
  - the effect of overall staffing levels and crew coordination for risk-important HAs
  - the effect of overall staffing levels and the coordination of personnel on human errors associated with the use of advanced technology

- HSI Design
  - staffing demands resulting from the locations and use (especially concurrent use) of controls and displays
  - the requirements for coordinated actions between individuals
  - decreases the availability or accessibility of information needed by personnel due to plant system and HFE modifications
  - the physical configuration of the control room and control consoles
  - the availability of plant information from individual workstations and group-view interfaces

- Procedure Development
  - staffing demands resulting from requirements for concurrent use of multiple procedures
  - personnel skills, knowledge, abilities, and authority identified in procedures

- Training Program Development
  - crew coordination concerns that are identified during the development of training

6.5 Sources of Additional Information

The following documents may be used for additional information (per Section 1.2.2):

10 CFR 50.47: *U.S. Code of Federal Regulations*, Part 50, "Domestic Licensing of Production and Utilization Facilities," Title 10, "Energy."

10 CFR 50.54: *U.S. Code of Federal Regulations*, Part 50, "Domestic Licensing of Production and Utilization Facilities," Title 10, "Energy."

10 CFR 26: *U.S. Code of Federal Regulations*, Part 26, "Fitness for Duty Programs," Title 10, "Energy."

ANSI/ANS 58.8: *Time Response Design Criteria for Safety-Related Operator Actions* (American Nuclear Society, 1994).

ANSI/ANS 3.1: *Selection, Qualification, and Training of Personnel for Nuclear Power Plants*, (American Nuclear Society, 1993).

ANSI/ANS 3.5: *Nuclear Power Plant Simulators for Use in Operator Training* (American Nuclear Society, 1998).

Generic Letter No. 82-12: *Policy on Factors Causing Fatigue of Operating Personnel at Nuclear Reactors* (NRC, 1982).

Information Notice 95-48: *Results of Shift Staffing Study* (NRC, 1995).

Information Notice 97-78: *Crediting of Operator Actions in Place of Automatic Actions and Modifications of Operator Actions, Including Response Times* (NRC, 1997).

NUREG-0654: *Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants* (NRC, 1980).

NUREG-0737 and Supplements: *Clarification of TMI Action Plan Requirements* (NRC, 1980).

NUREG-0800: *Standard Review Plan*, Sections 13.1.1 - 13.1.3 (NRC, 1999).

Regulatory Guide 1.114: *Guidance to Operators at the Controls and to Senior Operators in the Control Room of a Nuclear Power Unit* (NRC , 1986).

Regulatory Guide 1.149: *Nuclear Power Plant Simulators for Use in Operator Training* (NRC, 2001).

Regulatory Guide 1.8: *Personnel Selection and Training* (NRC, 2000).

7 HUMAN RELIABILITY ANALYSIS

7.1 Background

Human reliability analysis (HRA) seeks to evaluate the potential for, and mechanisms of, human error that may affect plant safety. Thus, it is an essential element in achieving the HFE design goal of providing a design that will minimize personnel errors, allow their detection, and provide recovery capability.

The HRA should be conducted as an integrated activity to support both the HFE design and PRA activities. Figure 7.1 illustrates the relationship between the PRA/HRA and the rest of the HFE program, including the concept of an initial PRA/HRA and then a final one at completion of design. The quality of the HRA depends in large part on the analyst's understanding of personnel tasks, the information related to those tasks, and the factors that influence human performance of those tasks. The development of information to facilitate the understanding of causes and modes of human error is an important human factors activity. The HRAs should make use of descriptions and analyses of operator functions and tasks as well as the operational characteristics of HSIs. HRA can provide valuable insight into desirable characteristics of the HSI design. Consequently, the HFE design effort should give special attention to those plant scenarios, risk-important human actions, and HSIs that have been identified by PRA/HRA as being important to plant safety and reliability.

The discussions in the remainder of this HRA element will have to be judgmentally applied in appropriate portions to the earliest PRA/HRA (depending on the amount of design information that is available) and applied in full to the final PRA/HRA. By developing an understanding of the causes, modes, and probabilities of human error, the HRA can provide valuable insights into the desirable characteristics of the design; consequently, special attention should be paid to those scenarios, HAs, and HFE components that were identified by HRA and PRA analyses as being important to the plant's safety and reliability.

The HRA could be performed iteratively as the design progresses. The PRA and HRA should be performed early in the design process to provide insights and guidance both for systems design and for HFE purposes. The robustness of the HRA depends, in large part, on the analyst's understanding of personnel tasks, the information related to them, and the factors which influence human performance. Accordingly, the HRA should be carried out interactively as the design progresses. At the very least, the initial PRA/HRA should be finalized when the plant design and HFE are complete.

Although there are many different approaches to the conduct of HRA, there are several analysis components that ensure the quality of the HRA. These include

- meeting all applicable 10 CFR 50.34 (f)(1)(I) requirements
- use of a multidisciplinary team to analyze human actions within the context of the PRA
- availability of information related to those factors that affect human performance, such as accident analyses (indicating time available for action), task analyses, procedures, and HSI design details
- consideration of the effects of advanced technology on human performance and the potential for different types of human error that may be associated with the technology
- detailed analyses of human actions with an emphasis on human error mechanisms
- availability of appropriate sources of human error data for the types of human actions that are modeled
- sensitivity and uncertainty analyses to evaluate human error probability estimates

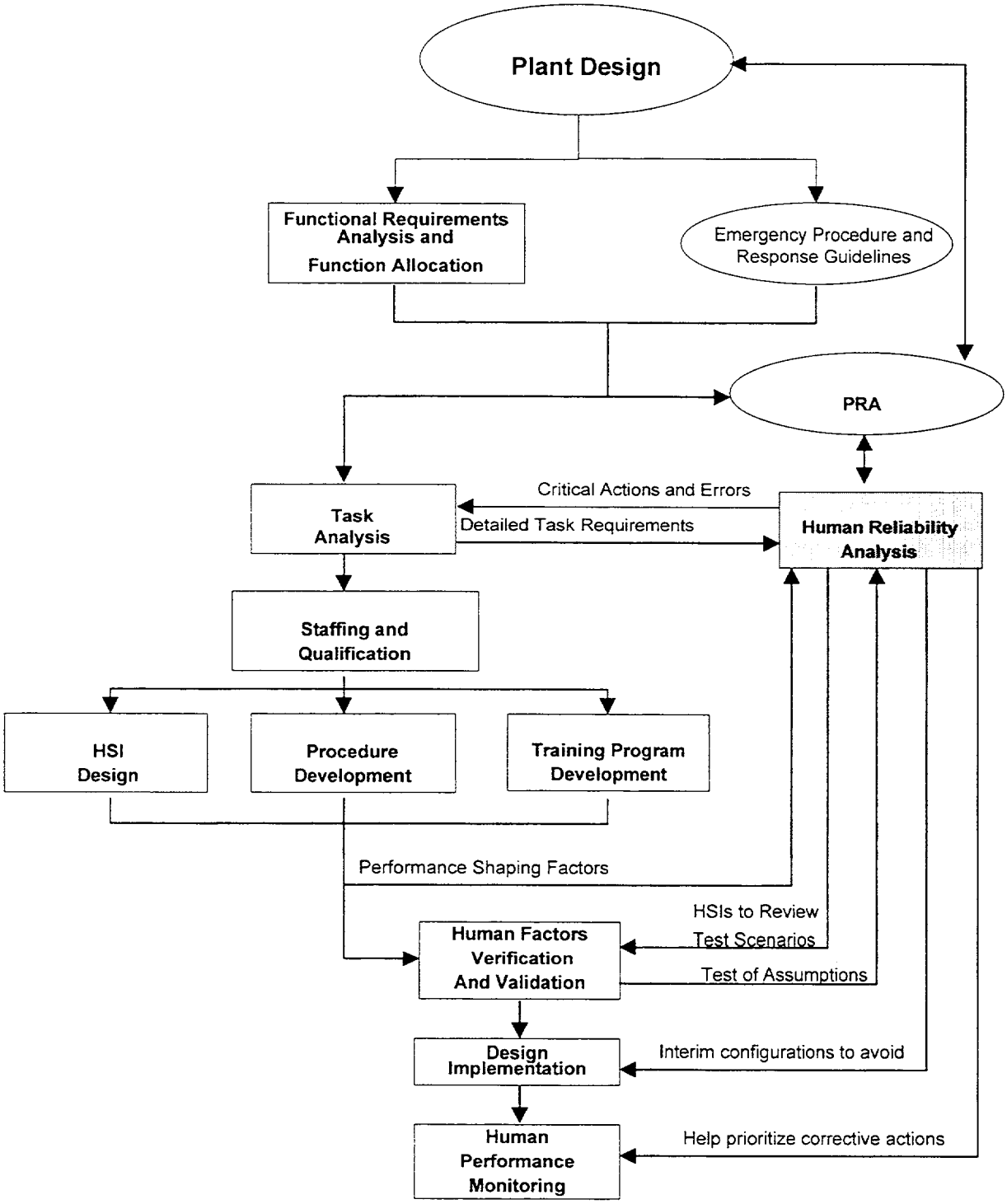

Figure 7.1 The Role of Human Reliability Analysis in the HFE Program

- integration of PRA and HRA activities into plant design activities
- thorough documentation of the HRA process

7.2 Objective

The objectives of this review are to ensure that (1) the applicant has addressed human-error mechanisms in the design of the HFE aspects of the plant to minimize the likelihood of personnel error, and ensure error are detected and recovered from; and (2) the HRA activity effectively integrates the HFE program and PRA and risk analysis.

7.3 Applicant Submittals

As per Section 1.2.1, item (3) Applicant Submittals, the applicant should provide for staff review an *implementation plan* for human reliability analysis. Upon completion of the applicant's efforts, a *results summary report* should be submitted so that the staff can review the applicant's evaluation of human-error mechanisms in the design of the HFE aspects of the plant and their integration of the HFE program and PRA and risk analysis using the criteria provided in Section 7.4 below.

7.4 Review Criteria

(1) Risk-important human actions should be identified from the PRA/HRA and used as input to the HFE design effort.

- These actions should be developed from the Level 1 (core damage) PRA and Level 2 (release from containment) PRA including both internal and external events. They should be developed using selected (more than one) importance measures and HRA sensitivity analyses to ensure that an important action is not overlooked because of the selection of the measure or the use of a particular assumption in the analysis.
- When upgrading plant systems, HSIs, procedures, and training the scope of the analysis should address personnel actions resulting from the modification and its interactions with the rest of the plant. Consideration should be given to the following effects of these modifications on the existing HRA:

  - whether the original HRA assumptions are valid for the modified design
  - whether the human errors analyzed in the existing HRA are still relevant
  - whether the probability of errors by operators and maintenance personnel may change
  - whether errors may be introduced that are not modeled by the existing HRA and PRA
  - whether the consequences of errors, established in the existing HRA, may change

(2) Risk-important HAs and their associated tasks and scenarios should be specifically addressed during function allocation analyses, task analyses, HSI design, procedure development, and training. This will help ensure that these tasks are well supported by the design and within acceptable human performance capabilities (e.g. within time and workload requirements).

(3) The use of PRA/HRA results by the HFE design team should be specifically addressed; that is, how are risk-important HAs addressed (through HSI design, procedural development, and training) under the HFE program to minimize the likelihood of operator error and provide for error detection and recovery capability.

(4) HRA assumptions such as decisionmaking and diagnosis strategies for dominant sequences should be validated by walkthrough analyses with personnel with operational experience using a plant-specific control room mockup or simulator. Reviews should be conducted before the final quantification stage of the PRA.

7.5 Sources of Additional Information

The following documents may be used for additional information (per Section 1.2.2):

IEEE Std. 1082-1997: *IEEE Guide for Incorporating Human Action Reliability Analysis for Nuclear Power Generating Stations*. (Institute of Electrical and Electronics Engineers, 1997).

NUREG-0800: *Standard Review Plan: Chapter 19, Use of Probabilistic Risk Assessment in Plant-Specific, Risk-Informed Decision Making: General Guidance* (NRC (1998)

NUREG-1560: *Individual Plant Examination Program: Perspectives on Reactor Safety and Plant Performance* (NRC, 1997).

NUREG-1624, Rev. 1.: *Technical Basis and Implementation Guidelines for A Technique for Human Event Analysis (ATHEANA)* (NRC, 2000).

NUREG/CR-6689: *Proposed Approach for Reviewing Changes to Risk-Important Human Actions* (Higgins and O'Hara, 2000).

Regulatory Guide 1.174: *An approach for using probabilistic risk assessment in risk-informed decisions on plant-specific changes to the licensing basis* (NRC, 1998).

Regulatory Guide 1.177: *An Approach for Plant-Specific, Risk-Informed Decisionmaking: Technical Specifications* (NRC, 1998).

Risk-informed inspection notebooks for each plant

8 HUMAN-SYSTEM INTERFACE DESIGN

8.1 Background

The HSI design process represents the translation of function and task requirements into HSI characteristics and functions. The HSI should be designed using a structured methodology that should guide designers in identifying and selecting candidate HSI approaches, defining the detailed design, and performing HSI tests and evaluations. It should cover the development and use of HFE guidelines that are tailored to the unique aspects of the applicants's design, e.g., a style guide to define the design-specific conventions. The availability of an HSI design methodology will help ensure standardization and consistency in applying HFE principles. The process and the rationale for the HSI design should be documented for review (including the results of trade-off studies, other analyses and evaluations, and the rationale for choosing design and evaluation tools).

Issues related to the detailed design of specific aspects of the HSIs should be resolved during HSI design activities rather than at verification and validation (V&V). For example, considerations as to acceptable display formats or alarm system processing should be resolved during the HSI design activities rather than deferred to V&V (as described in Section 11), at which point making modifications to the design is significantly more difficult.

8.2 Objective

The objective of this review element is to evaluate the process by which HSI design requirements are developed and HSI designs are identified and refined. The review should ensure that the applicant has appropriately translated functional and task requirements to the detailed design of alarms, displays, controls, and other aspects of the HSI through the systematic application of HFE principles and criteria.

8.3 Applicant Submittals

As per Section 1.2.1, item (3) Applicant Submittals, the applicant should provide for staff review an *implementation plan* for human-system interface design process. Upon completion of the applicant's efforts, a *results summary report* should be submitted so that the staff can review the applicant's development of design requirements and the HSI design using the criteria provided in Section 8.4 below.

8.4 Review Criteria

8.4.1 HSI Design Inputs

The following sources of information should provide input to the HSI design process:

(1) *Analysis of Personnel Task Requirements* - The analyses performed in earlier stages of the design process should be used to identify requirements for the HSIs. These analyses include:

- Operational experience review - Lessons learned from other complex human-machine systems, especially predecessor designs and designs involving similar HSI technology should be used as an input to HSI design.

- Functional requirement analysis and function allocation - The HSIs should support the operator's role in the plant, e.g., appropriate levels of automation and manual control.
- Task analysis - The set of requirements to support the role of personnel is provided by task analysis. The task analysis should identify:

- tasks that are necessary to control the plant in a range of operating conditions for normal through accident conditions;
- detailed information and control requirements (e.g., requirements for display range, precision, accuracy, and units of measurement);
- task support requirements (e.g., special lighting and ventilation requirements); and
- risk-important HAs and their associated performance shaping factors, as identified through HRA should be given special attention in the HSI design process.

- Staffing/qualifications and job analyses - The results of staffing/qualifications analyses should provide input for the layout of the overall control room and the allocation of controls and displays to individual consoles, panels, and workstations. They establish the basis for the minimum and maximum number of personnel to be accommodated and requirements for coordinating activities between personnel.

(2) *System Requirements* - Constraints imposed by the overall instrumentation and control (I&C) system should be considered throughout the HSI design process.

(3) *Regulatory Requirements* - Applicable regulatory requirements should be identified as inputs to the HSI design process.

(4) *Other Requirements* - The applicant should identify other requirements that are inputs to the HSI design.

8.4.2 Concept of Operations

(1) A concept of operations should be developed indicating crew composition and the roles and responsibilities of individual crew members based on anticipated staffing levels. The concept of operations should:

- Identify the relationship between personnel and plant automation by specifying the responsibilities of the crew for monitoring, interacting, and overriding automatic systems and for interacting with computerized procedures systems and other computerized operator support systems.
- Provide a high-level description of how personnel will work with HSI resources. Examples of the types of information that should be identified is the allocation of task to the main control room or local control stations, whether personnel will work at a single large workstation or individual workstations, what types of information each crew member will have access to, and what types of information should be displayed to the entire crew.
- Address the coordination of crew member activities, such as the interaction with auxiliary operators and coordination of maintenance and operations should be addressed.

8.4.3 Functional Requirement Specification

(1) Functional requirements for the HSIs should be developed to address:

- the concept of operations
- personnel functions and tasks that support their role in the plant as derived from function, task, and staffing/qualifications analyses
- personnel requirements for a safe, comfortable working environment

(2) Requirements should be established for various types of HSIs, e.g., alarms, displays, and controls.

8.4.4 HSI Concept Design

(1) The functional requirement specification should serve as the initial source of input to the HSI design effort. If the design is a direct evolution from a predecessor, rather than a new design concept, the criteria in this section should be considered relative to operating experience of the predecessor and the design features (e.g., aspects of the process, equipment, or operations) of the new design that may be different from the predecessor. Human performance issues identified from operating experience with the predecessor design should be resolved.

(2) Alternative approaches for addressing HSI functional requirements should be considered. A survey of the state-of-the-art in HSI technologies should be conducted to:

- support the development of concept designs that incorporate advanced HSI technologies
- provide assurance that proposed designs are technically feasible
- support the identification of human performance concerns and tradeoffs associated with various HSI technologies

(3) Alternative approaches for addressing HSI functional requirements should be considered. Evaluation methods can include operating experience and literature analyses, tradeoff studies, engineering evaluations and experiments.

(4) Alternative concept designs should be evaluated so that one can be selected for further development. The evaluation should ensure that the selection process is based on a thorough review of design characteristics and a systematic application of selection criteria. Tradeoff analyses, based on the selection criteria, should provide a rational basis for the selection of concept designs.

(5) HSI design performance requirements should be identified for components of the selected HSI concept design. These requirements should be based on the functional requirement specifications but should be refined to reflect HSI technology considerations identified in the survey of the state of the art in HSI technologies and human performance considerations identified in the human performance research.

8.4.5 HSI Detailed Design and Integration

(1) Design-specific HFE design guidance (style guide) should be developed. HFE Guidelines should be utilized in the design of the HSI features, layout, and environment.

- The content of the Style Guide should be derived from (1) the application of generic HFE guidance to the specific application, and (2) the development of the applicant's own guidelines based upon design-related analyses and experience. Guidelines that are not derived from generic HFE guidelines may be justified by the applicant based on an analysis of recent literature, analysis of current industry practices and operational experience, tradeoff studies and analyses, and the results of design engineering experiments and evaluations. The guidance should be tailored to reflect design decisions by the applicant to address specific goals and needs of the HSI design.
- The topics in the Style Guide should address the scope of HSIs included in the design and address the form, function, and operation of the HSIs as well as environmental characteristics relevant to human performance.
- The individual guidelines should be expressed in concrete, easily observable terms. In general, generic HFE guidelines should not be used in their abstract form. Such generic guidance should be translated into more specific design guidelines that can, as much as possible, provide unambiguous guidance to designers and evaluators. They should be detailed enough to permit their use by design personnel to achieve a consistent and verifiable design that meets the applicant's guideline.
- The Style Guide should provide procedures for determining where and how HFE guidance is to be used in the overall design process. The Style Guide should be written so it can be readily understood by designers. The Style Guide should support the interpretation and comprehension of design guidance by supplementing text with graphical examples, figures, and tables.
- The guidance should be maintained in a form that is readily accessible and usable by designers and that facilitates modification when the contents require updating as the design matures. Each guideline included in the guidance documentation should include a reference to the source upon which it is based.
- The Style Guide should address HSI modifications. This guidance should specifically address consistency in design across the HSIs.

(2) The HSI detailed design should support personnel in their primary role of monitoring and controlling the plant while minimizing personnel demands associated with use of the HSIs (e.g., window manipulation, display selection, display system navigation). NUREG-0700 describes high-level HSI design review principles that the detailed design should reflect.

(3) For risk-important HAs, the design should seek to minimize the probability that errors will occur and maximize the probability that an error will be detected if one should be made.

(4) When developing functional requirements for monitoring and control capabilities that may be provided either in the control room or locally in the plant, the following factors should be considered:

- communication, coordination, and workload
- feedback
- local environment

- inspection, test, and maintenance
- importance to safety.

(5) The layout of HSIs within consoles, panels, and workstations should be based upon (1) analyses of operator roles (job analysis) and (2) systematic strategies for organization such as arrangement by importance, frequency of use, and sequence of use.

(6) Personnel and task performance should be supported during minimal, nominal, and high-level staffing.

(7) The design process should take into account the use of the HSIs over the duration of a shift where decrements in performance due to fatigue may be a concern.

(8) HSI characteristics should support human performance under the full range of environmental conditions, e.g., normal as well as credible extreme conditions. For the main control room requirements should address conditions such as loss of lighting, loss of ventilation, and main control room evacuation. For the remote shutdown facility and local control stations, requirements should address constraints imposed by the ambient environment (e.g., noise, temperature, contamination) and by protective clothing (if necessary).

(9) The HSIs should be designed to support inspection, maintenance, test, and repair of (1) plant equipment and (2) the HSIs. The HSIs should be designed so that inspection, maintenance, test, and repair of the HSIs does not interfere with other plant control activities (e.g., maintenance tags should not block the operators' views of plant indications).

(10) The following considerations should be addressed in the review of design modifications:

- HSI modifications should be designed, to the extent possible, to be consistent with users' existing strategies for gathering and processing information and executing actions, identified in the task analysis. Consistency with existing strategies can reduce the learning personnel need to become proficient in using the modification.
- Design requirements for computer-based HSI modifications should include requirements for crew coordination and define design characteristics for supporting it. Design characteristics that may limit crew coordination include features that limit the ability of personnel to have a shared view of plant information (e.g., decision-aids and display devices that can only be accessed by one individual), maintain an awareness of others' actions, and communicate effectively with others from anticipated work locations.
- If the degree of integration between plant systems is changed, then design requirements should be developed to ensure that the HSIs support personnel in controlling these systems. The design requirements of the HSIs should ensure that the relationships between plant systems are clearly and accurately depicted.

8.4.6 HSI Tests and Evaluations

Testing and evaluation of HSI designs should be conducted throughout the HSI development process and evaluations should be performed iteratively. The methodology used for testing should be reviewed using the appropriate criteria provided below. Note the types of tests and evaluations performed will vary depending on the specific applicant's design process.

8.4.6.1 Trade-Off Evaluations

(1) Aspects of human performance that are important to task performance should be carefully selected and defined so that the differential effects of design options on human performance can be adequately considered in the selection of design approaches. The following factors should be considered when developing selection criteria:

- personnel task requirements
- human performance capabilities and limitations
- HSI system performance requirements
- inspection and testing requirements
- maintenance requirements
- use of proven technology and the operating experience of predecessor designs.

(2) The selection process should make explicit the relative benefits of design alternatives and the basis for their selection.

8.4.6.2 Performance-Based Tests

(1) Performance-based tests can have many different purposes, therefore, the hypotheses should be structured to address the specific questions being addressed.

(2) The general approach to testing should be based on the test objective. The design of performance-based tests should be driven by the purpose of the evaluation and the maturity of the design.

(3) The specific design features or characteristics of design features should be carefully defined. If the characteristics are to be manipulated in the test, i.e., systematically varied, the differences between test conditions should be specified in detail.

(4) The selection of testbeds for the conduct of performance-based tests should be based upon the requirements imposed by the test hypotheses and the maturity of the design.

(5) The selection of performance measures should be based on a consideration of:

- measurement characteristics
- identification and selection of variables to represent measures of the aspects of performance under investigation
- development of performance criteria.

(6) The selection of participants for HSI design tests should be based on the nature of the questions being addressed in test objectives and the level of design maturity.

(7) The test design should permit the observation of performance in a manner that avoids or minimizes bias, confounds, and error variance (noise).

(8) Test data should be analyzed using established analysis techniques.

(9) Design solutions, such as modifications of the HSIs or user training requirements, should be developed to address problems that are identified during the testing and evaluation of the HSI detailed design.

8.4.7 HSI Design Documentation

(1) The HSI design should be documented to include:

- the detailed HSI description including its form, function and performance characteristics
- the basis for the HSI requirements and design characteristics with respect to operating experience and literature analyses, tradeoff studies, engineering evaluations and experiments, and benchmark evaluations
- records of the basis of the design changes

(2) The outcomes of tests and evaluations performed in support of HSI design should be documented.

8.5 Sources of Additional Information

The following documents may be used for additional information (per Section 1.2.2):

ANSI/AIAA G-035-1992: *Guide to Human Performance Measurements* (American National Standards Institute, 1993).

ANSI HFS-100: *American National Standard for Human Factors Engineering of Visual Display Terminal Workstations* (American National Standards Institute, 1988).

BNL TR E2090-T4-1-9/96: *Human-System Interface Design Process and Review Criteria* (Stubler and O'Hara, 1996).

BNL TR E2090-T4-4-12/94, Rev. 1: *Group-View Displays* (Stubler and O'Hara, 1996).

EPRI NP-3659: *Human Factors Guide for Nuclear Power Plant Control Room Development* (Kinkade and Anderson, 1984).

EPRI NP-4350: *Human Engineering Design Guidelines for Maintainability* (Pack et al., 1985).

EPRI-ALWR URD: *Advanced Light Water Reactor Utility Requirements Document*, Volume II, *Evolutionary Plant*, Rev. 4 (Electric Power Research Institute, 1992).

IEC-964: *Design for Control Rooms of Nuclear Power Plants* (International Electrotechnical Commission, 1989).

IEEE Std. 1023-1988: *IEEE Guide to the Application of Human Factors Engineering to Systems, Equipment, and Facilities of Nuclear Power Generating Stations* (Institute of Electrical and Electronics Engineers, 1988).

NUREG/CR-6684: *Advance alarm systems: Guidance Development and Technical Basis* (Brown, et al., 2000)

NUREG/CR-6637: *Human-System Interface and Plant Modernization Process: Technical Basis and Human Factors Review Guidance* (Stubler, O'Hara, Higgins, and Kramer, 2000).

NUREG/CR-6393: *Integrated System Validation: Methodology and Review Criteria* (O'Hara, et al., 1997).

NUREG/CR-6635: *Soft Controls: Technical Basis and Human Factors Review Guidance* (W. Stubler, O'Hara, and Kramer, 2000).

NUREG/CR-6634: *Computer-Based Procedure Systems: Technical Basis and Human Factors Review Guidance* (O'Hara, Higgins, Stubler, and Kramer, 2000).

NUREG/CR-6633: *Advanced Information Systems: Technical Basis and Human Factors Review Guidance* (O'Hara, Higgins, and Kramer, 2000).

NUREG/CR-6636: *Maintenance of Digital Systems: Technical Basis and Human Factors Review Guidance* (Stubler, Higgins, and Kramer, 2000).

NUREG-0696: *Functional Criteria for Emergency Response Facilities* (NRC, 1980).

NUREG-0700: *Human-System Interface Design Review Guidelines* (NRC, 2002).

NUREG-0800: *Standard Review Plan, Chapter 18 Human Factors Engineering* (NRC, 1996).

Regulatory Guide 1.22: *Periodic Testing of Protection System Actuation Functions* (NRC, 1972).

Regulatory Guide 1.105: *Instrumentation Setpoints* (NRC, 1999).

Regulatory Guide 1.81: *Shared Emergency and Shutdown Electrical Systems for Multi-Unit NPPs* (NRC, 1975).

Regulatory Guide 1.97: *Instrumentation for Light-Water-Cooled Nuclear Power Plants to Assess Plant and Environmental Conditions During and Following an Accident* (NRC, 1983).

Regulatory Guide 1.62: *Manual Initiation of Protective Actions* (NRC, 1973).

Regulatory Guide 1.47: *Bypassed and Inoperable Status Indication for NPP Safety Systems* (NRC, 1973).

UCRL-15673: *Human Factors Design Guidelines for Maintainability of Department of Energy Nuclear Facilities* (Bongarra, et al., 1985).

9 PROCEDURE DEVELOPMENT

9.1 Background

Procedures are essential to plant safety because they support and guide personnel interactions with plant systems and their response to plant-related events. In the nuclear industry, procedure development has historically been considered the responsibility of individual utilities. Procedures should be derived from the same design process and analyses as the HSIs and training and subject to the same evaluation processes. The same human factors principles should be applied to both aspects of the interface to ensure complete integration and consistency.

For new plant designs and advanced reactors, the generic technical guidance (GTG), if available, and procedures should be developed as part of the same design process as the HSIs and training to ensure a high degree of integration and consistency. For plants that modernize, the procedure modifications should address all personnel tasks that are affected by the changes in plant systems and HSIs. Procedures should be developed or modified to reflect the characteristics and functions of the modification.

9.2 Objective

The objective of the review is to ensure that the applicant has applied HFE principles and guidance, along with all other design requirements, to develop procedures that are technically accurate, comprehensive, explicit, easy to use, and validated.

9.3 Applicant Submittals

As per Section 1.2.1, item (3) Applicant Submittals, the applicant should provide for staff review an *implementation plan* for procedure development. Upon completion of the applicant's efforts, a *results summary report* should be submitted so that the staff can review the applicant's efforts to develop procedures that are technically accurate, comprehensive, explicit, easy to use, and validated using the criteria provided in Section 9.4 below.

In addition, GTG and sample procedures should be available for review. The scope of the procedures covered in the element are

- GTG for emergency operating procedures (EOPs)
- plant and system operations (including startup, power, and shutdown operations)
- maintenance
- abnormal and emergency operations
- alarm response

9.4 Review Criteria

(1) Procedures should address applicable requirements of NUREG-0800 Section 13.5.

(2) The basis for procedure development should include:

- plant design bases
- system-based technical requirements and specifications
- task analyses results
- risk-important human actions identified in the HRA/PRA

- initiating events to be considered in the EOPs, including those events in the design bases
- GTG for EOPs

(3) A writers guide should be developed to establish the process for developing technical procedures that are complete, accurate, consistent, and easy to understand and follow. The guide should contain objective criteria so that procedures developed in accordance with it are consistent in organization, style, and content. The guide should be used for all procedures within the scope of this element. It should provide instructions for procedure content and format including the writing of action steps and the specification of acceptable acronym lists and acceptable terms to be used.

(4) The content of the procedures should incorporate the following elements:

- title and identifying information, such as number, revision, and date
- statement of applicability and purpose
- prerequisites
- precautions (including warnings, cautions, and notes)
- important human actions
- limitations and actions
- acceptance criteria
- checkoff lists
- reference material

(5) GTGs and EOPs should be symptom-based with clearly specified entry conditions.

(6) All procedures should be verified and validated, including:

- A review should be conducted to ensure they are correct and can be carried out.
- Their final validation should be performed in a simulation of the integrated system as part of the verification and validation activities described in the Human Factors Verification and Validation element, see Section 11.
- When procedures are modified, they should be verified to ensure their adequate content, format, and integration. The procedures also should be assessed through validation if a modification substantially changes personnel tasks that are significant to plant safety. The validation should ensure that the procedures correctly reflect the characteristics of the modified plant and can be carried out effectively to restore the plant.

(7) An analysis should be conducted to determine the impact of providing computer-based procedures (CBPs) and to specify where such an approach would improve procedure utilization and reduce operating crew errors related to procedure use. The justifiable use of CBPs over paper procedures should be documented. An analysis of alternatives in the event of loss of CBPs should be performed and documented.

(8) A plan for procedure maintenance and control of updates should be developed. Procedure modifications should be integrated across the full set of procedures; alterations in particular parts of the procedures should not conflict nor be inconsistent with other parts.

(9) The physical means by which operators access and use procedures, especially during operational events, should be evaluated as part of the HFE design process. This criterion generally applies to both hard-copy and computer-based procedures, although the nature of the issues differs somewhat depending on the implementation. For example, the process should address the storage of procedures, ease of operator access to the correct procedures, and laydown of hard-copy procedures for use in the control room, remote shutdown facility, and local control stations.

9.5 Sources of Additional Information

The following documents may be used for additional information (per Section 1.2.2):

ANS 3.2-1994: *Administrative Controls and Quality Assurance for the Operational Phase of NPPs* (American Nuclear Society, 1994).

IP 42700: *Plant Procedures.* (NRC, periodically updated).

IP 42001: *Emergency Operating Procedures.* (NRC, periodically updated).

NRC Regulatory Guide 1.33 (Rev. 2): *Quality Assurance Program Requirements* (NRC, 1978).

NUREG/CR-6634: *Computer-Based Procedure Systems: Technical Basis and Human Factors Review Guidance* (O'Hara, Higgins, Stubler, and Kramer, 2000).

NUREG/CR-5228: *Techniques for Preparing Flowchart Format Emergency Operating Procedures*, Volumes 1 and 2 (Barnes et al., 1989).

NUREG-0800: *Standard Review Plan* (NRC ,1999).

NUREG-0899: *Guidelines for the Preparation of Emergency Operating Procedures*(NRC, 1982).

NUREG-1358: *Lessons Learned From the Special Inspection Program for Emergency Operating Procedures*, Supplement 1 (NRC, 1992).

NUREG-1358: *Lessons Learned From the Special Inspection Program for Emergency Operating Procedures* (NRC, 1989).

NUREG/CR-5228: *Techniques for Preparing Flowchart-Format Emergency Operating Procedures*(Barnes et al. 1989).

10 TRAINING PROGRAM DEVELOPMENT

10.1 Background

Training of plant personnel is an important factor in ensuring safe and reliable operation of nuclear power plants. Training programs help to ensure plant personnel have the knowledge, skills, and abilities to properly perform their roles and responsibilities. Training design should be based on the systematic analysis of job and task requirements. Therefore, training program development should be coordinated with the other elements of the HFE design process.

10.2 Objective

The objective of this review is to ensure that the applicant has a systematic approach for the development of personnel training. The training development should include the following five activities:

- a systematic analysis of tasks and jobs to be performed
- development of learning objectives derived from an analysis of desired performance following training
- design and implementation of training based on the learning objectives
- evaluation of trainee mastery of the objectives during training
- evaluation and revision of the training based on the performance of trained personnel in the job setting

10.3 Applicant Submittals

As per Section 1.2.1, item (3) Applicant Submittals, the applicant should provide for staff review an *implementation plan* for training program development. Upon completion of the applicant's efforts, a *results summary report* should be submitted so that the staff can review the applicant's training program using the criteria provided in Section 10.4 below.

10.4 Review Criteria

The review criteria are organized into the following sections: General Approach, Organization of Training, Learning Objectives, Content of Training Program, Evaluation of Training, and Periodic Re-training.

10.4.1 General Approach

(1) A systems approach to the training of plant personnel should be developed that address applicable requirements of NUREG-0800 Section 13.2 ("Training"), as defined in 10 CFR 55.4, is required by 10 CFR 52.78 and 50.120.

(2) The overall scope of training should be defined including the following:

- categories of personnel (e.g., senior reactor operator) to be trained
- specific plant conditions (normal, upset, and emergency)
- specific operational activities (e.g., operations, maintenance, testing and surveillance)
- HSIs (e.g., in the main control room, emergency operations facility, remote shutdown panel, local control stations).

(3) The training program should ensure that personnel have the qualifications commensurate with the performance requirements of their jobs. Training should address:

- the full range of positions of operational personnel including licensed and nonlicensed personnel whose actions may affect plant safety
- the full range of plant functions and systems including those that may be different from those in predecessor plants (e.g., passive systems and functions)
- the full range of relevant HSIs (e.g., main control room, remote shutdown panel, local control stations) including characteristics that may be different from those in predecessor plants (e.g., display space navigation, operation of "soft" controls)
- the full range of plant conditions

10.4.2 Organization of Training

(1) The roles of all organizations, especially the applicant and vendors, should be specifically defined for the development of training requirements, development of training information sources, development of training materials, and implementation of the training program. For example, the role of the vendor may range from merely providing input materials (e.g., EPG) to conducting portions of specific training programs.

(2) The qualifications of organizations and personnel involved in the development and conduct of training should be defined.

(3) Facilities and resources such as plant-referenced simulator and part-task training simulators needed to satisfy training design requirements and the guidance contained in ANSI 3.5 and Regulatory Guide 1.149 should be defined.

10.4.3 Learning Objectives

(1) Learning objectives should be derived from the analysis that describes desired performance after training. This analysis should include but not be limited to training needs identified in the following:

- *Licensing Basis* - Final Safety Analysis Report, system description manuals and operating procedures, facility license and license amendments, licensee event reports, and other documents identified by the staff as being important to training
- *Operating Experience Review* - previous training deficiencies and operational problems that may be corrected through additional and enhanced training, and positive characteristics of previous training programs
- *Function Analysis and Allocation* - functions identified as new or modified
- *Task Analysis* - tasks identified during task analysis as posing unusual demands including new or different tasks, and tasks requiring a high degree if coordination, high workload, or special skills
- *Human Reliability Analysis* - requirements for coordinating individual roles to reduce the likelihood and/or consequences of human error associated with risk-important HAs and the use of advanced technology
- *HSI Design* - design features whose purpose or operation may be different from the past experience or expectations of personnel

- *Plant Procedures* - tasks that have been identified during procedure development as being problematic (e.g., procedure steps that have undergone extensive revision as a result of plant safety concerns)
- *Verification and Validation* (V&V) - training concerns identified during V&V, including HSI usability concerns identified during validation or suitability verification and operator performance concerns (e.g., misdiagnoses of plant event) identified during validation trials

(2) Learning objectives for personnel training should address the knowledge and skill requirements associated with all relevant dimensions of the trainee's job, such as interactions with the plant, the HSIs, and other personnel. Table 10.1, below, shows these dimensions.

Table 10.1 Some Knowledge and Skill Dimensions for Learning Objectives Identification

Topic	Knowledge	Skill
Plant Interactions	Understanding of plant processes, systems, operational constraints, and failure modes.	Skills associated with monitoring and detection, situation awareness, response planning and implementation.
HSI and Procedure Interactions	Understanding of procedures and HSI structure, functions, failure modes, and interface management tasks (actions, errors, and recovery strategies).	Skills associated with interface-management tasks.
Personnel Interactions (In the CR and in the plant)	Understanding information requirements of others, how actions should be coordinated with others, policies and constraints on crews' interaction.	Skills associated with crew's interactions (i.e., teamwork)

10.4.4 Content of Training Program

(1) The design of the training program should be defined to specify how learning objectives will be conveyed to the trainee. The definition should include:

- The use of lecture, simulator, and on-the-job training to convey particular categories of learning objectives should be defined.
- Specific plant conditions and scenarios to be used in training programs should be defined.
- Training implementation considerations such as the temporal order and schedule of training segments should be defined.

(2) Factual knowledge should be taught within the context of actual tasks so that personnel learn to apply it in the work environment. The context of the job should be defined, and it should be represented meaningfully to help trainees to link the knowledge to the job's requirements. Training that addresses theory should be integrated with training in using procedures.

(3) Training programs for developing skills should be structured so that the training environment is consistent with the level of skill being taught. It should support skill acquisition by allowing trainees to manage cognitive demands. For example, trainees should not be placed in environments teaching high-level skills, such as coordinating control actions among crew members, before they have mastered requisite, low-level skills, such as how to manipulate control devices.

(4) Training should address rules for decision-making related to plant systems, HSIs, and procedures. It should include rules for accessing and interpreting information and rules for interpreting symptoms of failures of systems, HSIs, and procedures. This training should cover acquiring new decision-making rules and eliminating existing ones that are not appropriate to the design.

10.4.5 Evaluation and Modification of Training

(1) Methods for evaluating the overall effectiveness of the training programs and trainee mastery of training objectives should be defined, including written and oral tests and review of personnel performance during walkthrough, simulator exercises, and on-the-job. Evaluation criteria for training objectives should be defined for individual training modules. Methods for assessing overall proficiency should be defined and coordinated with regulations, where applicable.

(2) Methods for verifying the accuracy and completeness of training course materials should be defined.

(3) Procedures for refining and updating the content and conduct of training should be established, including procedures for tracking training course modifications.

10.4.6 Periodic Retraining

(1) Personnel should undergo periodic retraining.

(2) The applicant should evaluate whether any changes or increases in retraining are warranted following plant modernization programs.

10.5 Sources of Additional Information

The following documents may be used for additional information (per Section 1.2.2):

10 CFR Part 55: *U.S. Code of Federal Regulations*, Part 55, "Operators' Licenses," Title 10, "Energy."

10 CFR 50.120: *U.S. Code of Federal Regulations*, Part 50, "Training and Qualification of Nuclear Power Plant Personnel," Title 10, "Energy."

ANSI/ANS 3.1-1993; R1999: *Selection, Qualification, and Training of Personnel for Nuclear Power Plants* (American Nuclear Society, 1999).

ANSI/ANS 3.5-1998: *Nuclear Power Plant Simulators for Use in Operator Training* (American Nuclear Society, 1998).

IP 41500: *Training and Qualification Effectiveness.* (NRC, periodically updated).

NUREG-0800: *Standard Review Plan*, Section 13.2, Training, (NRC, 1999)

NUREG-1220: *Training Review Criteria and Procedures* (NRC, Revised periodically).

Regulatory Guide 1.149: *Nuclear Power Plant Simulators for Use in Operator Training* (NRC, 2001).

Regulatory Guide 1.8: *Personnel Selection and Training* (NRC, 2000).

11 HUMAN FACTORS VERIFICATION AND VALIDATION

11.1 Background

Verification and validation (V&V) evaluations comprehensively determine that the design conforms to HFE design principles and that it enables plant personnel to successfully perform their tasks to achieve plant safety and other operational goals. This section describes four major activities: Operational Condition Sampling, Design Verification, Integrated System Validation, and Human Engineering Discrepancies (HEDs) Resolution (see Figure 11.1). The sampling of operational conditions to support V&V tests is important because reviews of new plants and significant HSI modifications can involve hundreds or thousands of individual HSI components. It would be impractical and unnecessary to review all of them. Therefore, the applicant can employ a sampling strategy to guide the selection of HSIs to review.

It should be noted that with the exception of Integrated System Validation, the majority of this section mainly addresses verification of HSIs. There are separate NRC reviews to validate procedures and training programs.

The review involves two types of Design Verification: HSI Task Support Verification and HFE Design Verification. HSI Task Support Verification is an evaluation to verify that the HSI supports personnel task requirements as defined by task analyses. HEDs are identified for: (1) personnel task requirements that are not fully supported by the HSI, and (2) the presence of HSI components which may not be needed to support personnel tasks. HFE Design Verification is an evaluation to verify that the HSI is designed to accommodate human capabilities and limitations as reflected in HFE guidelines such as those provided in NUREG-0700. HEDs are identified if the design is inconsistent with HFE guidelines.

Integrated System Validation is an evaluation using performance-based tests to determine whether an integrated system design (i.e., hardware, software, and personnel elements) meets performance requirements and acceptably supports safe operation of the plant. HEDs are identified if performance criteria are not met.

HED Resolution is an evaluation to ensure that the HEDs identified during the V&V activities have been acceptably assessed and resolved. HED Resolution is an activity that should be performed iteratively with V&V. That is, the applicant may address and resolve issues identified during a V&V activity prior to conducting other V&V activities. The preferred order is HSI Task Support Verification, HFE Design Verification, and Integrated System Validation, although iteration may be necessary.

Many design documents (e.g., ISO 11064) recommend conducting V&V throughout the design process. This document agrees with that recommendation, with these activities called "HSI Tests and Evaluations" (see the HSI Design element, Section 8.4.6). Such tests are distinguished from V&V since they are activities whereby HSI subsystem design issues (such as the coding techniques used in the alarm system) are explored and evaluated. V&V is considered a test that final design requirements are met.

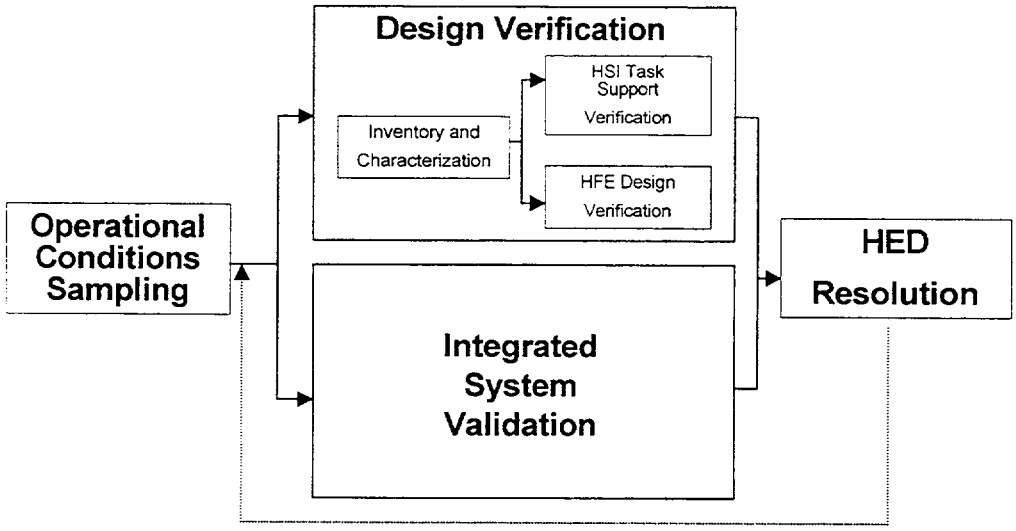

Figure 11.1 Overview of Verification and Validation Activities

11.2 Objective

Detailed review objectives for the various aspects of V&V are provided for each subsection of Section 11.4 below.

11.3 Applicant Submittals

As per Section 1.2.1, item (3) Applicant Submittals, the applicant should provide for staff review an *implementation plan* for HFE V&V. Upon completion of the applicant's efforts, a *results summary report* should be submitted so that the staff can review the applicant's V&V evaluations using the criteria provided in Section 11.4 below.

In addition to the review of the applicant's documentation, the NRC staff may also verify a sample of V&V activities to confirm the results and observe the integrated system validation trials as part of the review.

11.4 Review Criteria

11.4.1 Operational Conditions Sampling

The sampling methodology will identify a range of operational conditions to guide V&V activities. The review of operational conditions sampling considers the dimensions to be used to identify and select conditions and their integration into scenarios.

11.4.1.1 Operational Conditions Sampling Review Objectives

The review should ensure that the applicant has identified a sample of operational conditions that (1) includes conditions that are representative of the range of events that could be encountered during operation of the plant, (2) reflects the characteristics that are expected to contribute to system performance variation, and (3) considers the safety significance of HSI components. These sample characteristics are best identified through the use of a multidimensional sampling strategy to ensure that variation along important dimensions is included in the V&V evaluations. The review criteria, therefore, address the sampling dimensions used and the identification of scenarios based on those dimensions. In addition, special considerations for plant modernization and modification programs are identified.

11.4.1.2 Operational Conditions Sampling Review Criteria

11.4.1.2.1 Sampling Dimensions

The following sampling dimensions are addressed below: plant conditions, personnel tasks, and situational factors known to challenge personnel performance.

(1) The following plant conditions should be included:

- normal operational events including plant startup, plant shutdown or refueling, and significant changes in operating power
- failure events, e.g.,
  - instrument failures [e.g., safety-related system logic and control unit, fault tolerant controller, local "field unit" for multiplexer (MUX) system, MUX controller, and break in MUX line] including I&C failures that exceed the design basis, such as a common mode I&C failure during an accident
  - HSI failures (e.g., loss of processing and/or display capabilities for alarms, displays, controls, and computer-based procedures).
- transients and accidents, e.g.,
  - transients (e.g., turbine trip, loss of off-site power, station blackout, loss of all feedwater, loss of service water, loss of power to selected buses or main control room (MCR) power supplies, and safety and relief valve transients)
  - accidents (e.g., main steam line break, positive reactivity addition, control rod insertion at power, anticipated transient without scram, and various-sized loss-of-coolant accidents)
  - reactor shutdown and cooldown using the remote shutdown system.
- reasonable, risk-significant, beyond-design-basis events, which should be determined from the plant specific PRA.
- consideration of the role of the equipment in achieving plant safety functions [as described in the plant safety analysis report (SAR)] and the degree of interconnection with other plant systems. A system that is interconnected with other systems could cause the failure of other systems because the initial failure could propagate over the connections. This consideration is especially important when assessing non-class 1E electrical systems.

(2) The following types of personnel tasks should be included:

- *Risk-significant HAs, systems, and accident sequences* - All risk-important HAs should be included in the sample. These include identified in the PRA and those identified as risk-important in the SAR and NRC's safety evaluation report (SER) should be included. Situations where human monitoring of an automatic system is risk-important should be considered. Additional factors should be sampled that contribute highly to risk, as defined by the PRA, including:
  - dominant human actions (selected via sensitivity analyses)
  - dominant accident sequences
  - dominant systems (selected via PRA importance measures such as Risk Achievement Worth or Risk Reduction Worth)

- *OER-identified difficult tasks* - The sample should include all personnel tasks identified as problematic during the applicant's review of operating experience.

- *Range of procedure guided tasks* - These are tasks that are well defined by normal, abnormal, emergency, alarm response, and test procedures. Rule-based decision-making requires that the operator can understand and execute the specified steps. Regulatory Guide 1.33, Appendix A, contains several categories of "typical safety-related activities that should be covered by written procedures." The sample should include appropriate procedures in each relevant category:
  - administrative procedures
  - general plant operating procedures
  - procedures for startup, operation, and shutdown of safety-related systems
  - procedures for abnormal, off normal, and alarm conditions
  - procedures for combating emergencies and other significant events
  - procedures for control of radioactivity
  - procedures for control of measuring and test equipment and for surveillance tests, procedures, and calibration
  - procedures for performing maintenance
  - chemistry and radiochemical control procedures.

- *Range of knowledge-based tasks* - these are tasks that are not as well defined by detailed procedures. Knowledge-based decision-making requires greater reasoning about safety and operating goals and the various means of achieving them. A situation may require knowledge-based decision-making if the rules do not fully address the problem, or the selection of appropriate rule is not clear. An example in a pressurized water reactor plant may be the difficulty in diagnosing a steam generator tube rupture (SGTR) with a failure of radiation monitors on the secondary side of the plant because (1) there is no main indication of the rupture (the presence of radiation in secondary side), and (2) the other effects of the rupture (i.e., slight changes in pressures and levels on the primary and secondary sides) may be attributed to other causes. While the operators may use procedures to treat the symptoms of the event, the determination that the cause is a SGTR may require situation assessment based on an understanding of the plant's design and the possible combinations of failures that could result in the observed symptoms. Errors in

rule-based decision-making result from selecting the wrong rule or incorrectly applying a rule. Error in knowledge-based decision-making result from mistakes in higher-level cognitive functions such as judgment, planning, and analysis. The latter are more likely to occur in complex failure events where the symptoms do not resemble the typical case, and thus, are not amenable to pre-established rules.

- *Range of human cognitive activities* -The sample should include the range of cognitive activities performed by personnel, including:
  - detection and monitoring (e.g., of critical safety-function threats)
  - situation assessment (e.g., interpretation of alarms and displays for diagnosis of faults in plant processes and automated control and safety systems)
  - response planning (e.g., evaluating alternatives for recovery from plant failures)
  - response implementation (e.g., in-the-loop control of plant systems, assuming manual control from automatic control systems, and carrying out complicated control actions)
  - obtaining feedback (e.g., of the success of actions taken)

- *Range of human interactions* - The sample should reflect the range of interactions among plant personnel, including tasks that are performed independently by individual crew members and tasks that are performed by crew members acting as a team. These interactions among plant personnel should include:
  - between main control room operators (e.g., operations, shift turnover walkdowns)
  - main control room operators and auxiliary operators
  - main control room operators and support centers (e.g., the technical support center and the emergency offsite facility)
  - main control room operators with plant management, NRC, and other outside organizations
- Tasks that are performed with high frequency.

(3) The sample should reflect a range of situational factors that are known to challenge human performance, such as:

- *Operationally difficult tasks* - The sample should address tasks that have been found to be problematic in the operation of NPPs, e.g., procedure versus situation assessment conflicts. The specific tasks selected should reflect the operating history of the type of plant being validated (or the plant's predecessor).
- *Error-forcing contexts* - Situations specifically designed to create human errors should be included to assess the error tolerance of the system and the capability of operators to recover from errors should they occur.
- *High-workload conditions* - The sample should include situations where human performance variation due to high workload and multitasking situations can be assessed.
- *Varying-workload situations* - The sample should include situations where human performance variation due to workload transitions can be assessed. These include conditions that exhibit (1) a sudden increase in the number of signals that must be

detected and processed following a period in which signals were infrequent and (2) a rapid reduction in signal detection and processing demands following a period of sustained high task demand.

- *Fatigue and circadian factors* - The sample should include situations where human performance variation due to personnel fatigue and circadian factors can be assessed
- *Environmental factors* - The sample should include situations where human performance variation due to environmental conditions such as poor lighting, extreme temperatures, high noise, and simulated radiological contamination can be assessed.

11.4.1.2.2 Identification of Scenarios

(1) The results of the sampling should be combined to identify a set of scenarios to guide subsequent analyses. A given scenario may combine many of the characteristics identified by the operational event sampling.

(2) The scenarios should not be biased in the direction of over representation of the following:

- scenarios for which only positive outcomes can be expected
- scenarios that for integrated system validation are relatively easy to conduct administratively (scenarios that place high demands, data collection or analysis are avoided).
- scenarios that for integrated system validation are familiar and well structured (e.g., which address familiar systems and failure modes that are highly compatible with plant procedures such as "textbook" design-basis accidents)

11.4.1.2.3 Special Considerations for Plant Modernization Programs

When evaluating plant modifications, the following factors should be addressed when identifying operational conditions:

(1) The operational conditions should reflect tasks that involve the modification, rather than the entire range of topics discussed above for Personnel Tasks.

(2) For integrated system validation, the operational conditions should address the transfer of learning effects on personnel performance when a modification replaces an old HSI or procedure. (Negative transfer of learning effects may occur when the new and old components are different and impose different demands on personnel.)

(3) For integrated system validation, when both old and new versions of the same HSI components with different means of presentation and methods of operation are permanently present in the HSI, evaluations should ensure that personnel can alternate their use of these HSI components without degrading their performance.

(4) Where old HSI components that are to be deactivated and left in place in the HSI, conditions should be identified for integrated system validation that would test the potential for task interference. For example, the presence of deactivated HSI components may cause visual clutter that interferes with the ability of operators to locate and use other HSI components.

11.4.2 Design Verification

11.4.2.1 Inventory and Characterization

11.4.2.1.1 Inventory and Characterization Review Objectives

The objective of this review is to ensure that the applicant's HSI inventory and characterization accurately describes all HSI displays, controls, and related equipment that are within the defined scope of the HSI design review.

11.4.2.1.2 Inventory and Characterization Review Criteria

(1) *Scope* - The applicant should develop an inventory of all HSI components associated with the personnel tasks that are required based on the identified operational conditions. The inventory should include aspects of the HSI that are used for interface management such as navigation and display retrieval in addition to those that control the plant.

(2) *HSI Characterization* - The inventory should describe the characteristics of each HSI component within the scope of the review. The following is a minimal set of information for the characterization:

- a unique identification code number or name
- associated plant system and subsystem
- associated personnel functions/subfunction
- type of HSI component
  - computer-based control (e.g., touch screen or cursor-operated button and keyboard input)
  - hardwired control (e.g., J-handle controller, button, and automatic controller)
  - computer-based display (e.g., digital value and analog representation)
  - hardwired display (e.g., dial, gauge, and strip chart recorder)
- display characteristics and functionality [e.g., plant variables/parameters, units of measure, accuracy of variable/parameter, precision of display, dynamic response, and display format (bar chart, and trend plot)]
- control characteristics and functionality [e.g., continuous versus discrete settings, number and type of control modes, accuracy, precision, dynamic response, and control format (method of input)]
- user-system interaction and dialog types (e.g., navigation aids and menus)
- location in data management system (e.g., identification code for information display screen)
- physical location in the HSI (e.g., control panel section), if applicable

Photographs, copies of VDU screens, and similar samples of HSI components should be included in the HSI inventory and characterization.

(3) *Information Sources* - The inventory should be based on the best available information sources. Equipment lists, design specifications, and drawings describe HSI components. These descriptions should be compared by directly observing the components, both hardwired and computer-generated, to assure that the inventory accurately reflects their current state.

11.4.2.2 HSI Task Support Verification

11.4.2.2.1 HSI Task Support Verification Review Objectives

The objective of this review is to ensure that the applicant verifies that the HSI provides all alarms, information, and control capabilities required for personnel tasks.

11.4.2.2.2 HSI Task Support Verification Review Criteria

(1) *Criteria Identification* - The criteria for Task Support Verification come from task analyses of HSI requirements for performance of personnel tasks that are selected operational conditions should be defined.

(2) *General Methodology* - The HSIs and their characteristics (as defined in the HSI inventory and characterization) should be compared to the personnel task requirements identified in the task analysis.

(3) *Task Requirements Deficiencies* - HEDs should be identified when:

- an HSI needed for task performance (e.g., a required control or display) is not available
- HSI characteristics do not match the personnel task requirements, e.g., a display shows the required plant parameter but not the range or precision needed for the task

(4) *Unnecessary HSI Components* - An HED should be identified for HSIs that are available in the HSI but are not required for any task. Unnecessary HSIs introduce clutter and can distract personnel for the selection of appropriate HSIs. It is important to verify that the HSI is actually unnecessary. Appropriate HSI components may not appear to be associated with personnel tasks for the following reasons:

- The HSI component is required for a task that was not addressed by the task analysis (e.g., it was not within the scope of the design review).
- The task analysis was incomplete, and thus overlooked the need for the HSI component.
- The HSI component only partially meets the personnel task requirements that were established.

If an HSI component has no associated personnel tasks because the function and task analysis was incomplete, then the applicant should identify and resolve any shortcomings in that analysis.

(5) *Additional Methodology Considerations for Plant Modifications* - the following considerations should be addressed:

- HSI Task Support Verification should address all aspects of HSIs described above that are relevant to the modification. For modifications to plant systems that do not include

modifications of the HSIs, task-support verification should identify any new demands for monitoring and control, and determine whether they are adequately addressed by the existing HSI design.

- HSI Task Support Verification should address modification configurations in which old HSIs are permanently deactivated, but not removed (e.g., abandoned in place). Criterion 4, above, states that the HSIs should not contain any information, displays, or controls that do not support personnel tasks. This verification should identify deactivated HSIs that may have potentially negative effects on personnel performance, such as obstructing the view of important information or adding visual clutter which may interfere with monitoring. Deactivated HSIs requiring further evaluation through HFE design verification or integrated system validation should be identified.
- HSI Task Support Verification should address temporary configurations of the HSIs and plant systems that may be created during implementation of the modification, and used by operations and maintenance personnel when the plant is not shutdown. These configurations may include:

  - the use of HSIs that differ from the intended final design
  - combinations of HSIs and system configurations that differ from both the original and the intended final designs.

  For each temporary HSI configuration, the task requirements of personnel should be identified and compared to the information and control capabilities provided. For example, if a temporary configuration of plant systems introduces special monitoring requirements, then the HSIs should provide the necessary information.

(6) *HED Documentation* - HEDs should be documented to identify the HSI, the relevant task criterion, and basis for the deficiency (what aspect of the HSI has been identified as not meeting task requirements).

11.4.2.3 HFE Design Verification

11.4.2.3.1 HFE Design Verification Review Objective

The objective of this review is to ensure that the applicant verifies that the characteristics of the HSI and the environment in which it is used conform to HFE guidelines. The aspects of the applicant's HFE Design Verification that are addressed in the staff's evaluation are discussed below.

11.4.2.3.2 HFE Design Verification Review Criteria

(1) *Criteria Identification* - The criteria for this verification are the HFE guidelines. The selection of guidelines used in the review depends upon the characteristics of the HSI components included in the scope of the review, as defined in the HSI characterization. It also depends upon whether the applicant has developed a style guide (design-specific HFE guideline document). When a style guide is used by the applicant, its acceptability should be reviewed by the staff. The procedures involved are described in Section 8.4.5. The HFE guidelines contained in NUREG-0700 may be used to support the staff's review of the guidance contained in an applicant's style guide. When an NRC reviewed style guide has been used, it can provide the criteria for HFE design verification.

When no style guide is available, the guidelines in NUREG-0700 can be used for the HFE design verification. However, since not all of these guidelines will be applicable to each review, the selection of guidelines should be based on the characteristics of the HSI components being evaluated. A subset of guidelines appropriate to the specific design implementation should be identified based on the HSI characterization.

(2) *General Methodology* - The characteristics of the HSI components should be compared with HFE guidelines. These guidelines are applicable to different aspects of the design: task-independent features (e.g., font size), task-specific features (e.g., scale units), and task-integration features (e.g., proximity of control-display).

A single guideline may apply to many identical HSI components, especially in the case of significant HSI modifications and HSIs for new plants. In addition, some environmental considerations (e.g., lighting) may be applicable. To simplify the application of guidelines and reduce redundancy when reporting findings, the guidelines may be applied to features of the HSI as follows:

- *Global features* - global HSI features are those relating to the configurational and environmental aspects of the HSI, such as MCR layout, general workstation configuration, lighting, noise, heating, and ventilation. These aspects of the review, e.g., MCR lighting, tend to be evaluated only once.
- *Standardized features* - standardized features are those that were designed using HFE guidelines applied across individual controls and displays (e.g., display screen organization, display format conventions, and coding conventions). Therefore, their implementation should be more consistent across the interface than features that were not designed with guidelines. Thus, for example, if display labeling is standardized by the applicant's HFE guidelines (style guide), which have been accepted by the NRC, then display labels can be spot-checked rather than being verified individually.
- *Detailed features* - detailed features are the aspects of individual HSIs that not addressed by general HFE guidelines. The latter can be expected to be more variable than the standardized design features.

For each guideline, it should be determined whether the HSI is "acceptable" or "discrepant" from the guideline (therefore, potentially unacceptable), an HED. Acceptable should be indicated only if there is total compliance, i.e., only if every instance of the item is fully consistent with the criteria established by the HFE guidelines. If there is any instance of noncompliance, full or partial, then an evaluation of discrepant should be given, and a notation made as to where noncompliance occurs.

Discrepancies should be evaluated as potential indicators of additional issues. For example, identifying an inappropriate format for presenting data on an individual display should be considered a potential sign that other display formats could be incorrectly used or that the observed format is inappropriately used elsewhere. As a result, the sampling strategy could be modified to encompass other display formats. In some cases, discovering these discrepancies could warrant further review in the identified areas of concern.

(3) *Additional Methodology Considerations for Plant Modifications* - the following considerations should be addressed

- The scope of HFE design verification may be restricted to the modified HSIs and their interactions with the rest of the HSIs.
- When both old and new versions of similar HSIs are permanently present in design, this verification should ensure that their means of presentation and methods of operation are compatible, such that personnel performance will not be impaired when the use of old and new components is alternated.
- HEDs should be identified for the following:
  - failure to meet "crew-identified" functionality in addition to that specified by system designers. When a digital system replaces an existing system, it is important to make sure that all operational uses of the former system have been addressed, even those that were not intended in the original design. The replacement system's design should consider the actual usage of the former system
  - poor integration with the rest of the HSI
  - poor integration with procedures and training.
- Temporary configurations of the HSIs and plant systems, which may be used by operations and maintenance personnel when the plant is not shutdown, should be reviewed to ensure that their design is consistent with the principles of good HFE design, including consistency with the rest of the HSIs.

(4) *HED Documentation* - HEDs, should be documented by the applicant in terms of the HSI component involved and how its characteristics depart from a particular guideline.

11.4.3 Integrated System Validation

11.4.3.1 Integrated System Validation Review Objective

Integrated system validation is the process by which an integrated system design (i.e., hardware, software, and personnel elements) is evaluated using performance-based tests to determine whether it acceptably supports safe operation of the plant. It is intended to evaluate the acceptability of those aspects of the design that cannot be determined though such analytical means as HSI task-support verification and HFE design verification.

Plant personnel should perform operational events using a simulator or other suitable representation of the system to determine its adequacy to support safety operations. This should be undertaken after significant HEDs that were identified in verification reviews have been resolved, since these will negatively effect performance and, therefore, the results of validation. (See O'Hara, et al., 1997 for a more detailed discussion of integrated system validation methodology.)

For the case of plant modifications, the applicability and scope of integrated system validation may vary. An integrated system validation should be reviewed for all modifications that may (1) change personnel tasks; (2) change tasks demands, such as changing task dynamics, complexity, or workload; or (3) interact with or affect HSIs and procedures in ways that may degrade performance. Integrated system validation may not be needed when a modification results in minor changes to personnel tasks such that they may reasonably be expected to have little or no overall effect on workload and the likelihood of error. The aspects of the validation that are addressed in the staff's evaluation are discussed below.

11.4.3.2 Integrated System Validation Review Criteria

11.4.3.2.1 Test Objectives

(1) Detailed objectives should be developed to provide evidence that the integrated system adequately supports plant personnel in the safe operation of the plant. The test objectives and scenarios should be developed to address aspects of performance that are affected by the modification design, including personnel functions and tasks affected by the modification. The objectives should be to:

- Validate the role of plant personnel.
- Validate that the shift staffing, assignment of tasks to crew members, and crew coordination (both within the control room as well as between the control room and local control stations and support centers) is acceptable. This should include validation of the nominal shift levels, minimal shift levels, and shift turnover.
- Validate that for each human function, the design provides adequate alerting, information, control, and feedback capability for human functions to be performed under normal plant evolutions, transients, design-basis accidents, and selected, risk-significant events that are beyond-design basis.
- Validate that specific personnel tasks can be accomplished within time and performance criteria, with a high degree of operating crew situation awareness, and with acceptable workload levels that provide a balance between a minimum level of vigilance and operator burden. Validate that the operator interfaces minimize operator error and provide for error detection and recovery capability when errors occur.
- Validate that the crew can make effective transitions between the HSIs and procedures in the accomplishment of their tasks and that interface management tasks such as display configuration and navigation are not a distraction or undue burden.
- Validate that the integrated system performance is tolerant of failures of individual HSI features.
- Identify aspects of the integrated system that may negatively effect integrated system performance.
- For modifications that change plant systems but do not modify the HSI, validation can provide evidence about the adequacy of the existing HSIs, procedures, and training for supporting personnel performance. The staff should ensure that the applicant validates that the functions and tasks allocated to plant personnel can be accomplished effectively when the integrated design is implemented.

11.4.3.2.2 Validation Testbeds

A testbed is the HSI representation used to perform validation evaluations. One approach to identifying a validation testbed that is consistent with the following review criteria, is to use the American National Standard "Nuclear power plant simulators for use in operator training," (ANSI/ANS 3.5-1998) as a guide.

(1) *Interface Completeness* - The testbed should completely represent the integrated system. This should include HSIs and procedures not specifically required in the test scenarios. For example, adjacent controls and displays may affect the ways in which personnel use those that are addressed by a particular validation scenario.

(2) *Interface Physical Fidelity* - A high degree of physical fidelity in the HSIs and procedures should be represented, including presentation of alarms, displays, controls, job aids, procedures, communications, interface management tools, layout and spatial relationships.

(3) *Interface Functional Fidelity* - A high degree of functional fidelity in the HSIs and procedures should be represented. All HSI functions should be available. High functional fidelity includes HSI component modes of operation, i.e., the changes in functionality that can be invoked on the basis of personnel selection and/or plant states.

(4) *Environment Fidelity* - A high degree of environment fidelity should be represented. The lighting, noise, temperature, and humidity characteristics should reasonably reflect that expected. Thus, noise contributed by equipment, such as air handling units and computers should be represented in validation tests.

(5) *Data Completeness Fidelity* - Information and data provided to personnel should completely represent the plant systems monitored and controlled from that facility.

(6) *Data Content Fidelity* - A high degree of data content fidelity should be represented. The information and controls presented should be based on an underlying model that accurately reflects the reference plant. The model should provide input to the HSI in a manner such that information accurately matches that which will actually be presented.

(7) *Data Dynamics Fidelity* - A high degree of data dynamics fidelity should be represented. The process model should be capable of providing input to the HSI in a manner such that information flow and control responses occur accurately and in a correct response time; e.g., information should be provided to personnel with the same delays as would occur in the plant.

(8) For important actions at complex HSIs remote from the main control room, where timely and precise human actions are required, the use of a simulation or mockup should be considered to verify that human performance requirements can be achieved. (For less risk-important HAs or where the HSIs are not complex, human performance may be assessed based on analysis such as task analysis rather than simulation.)

(9) The testbeds should be verified for conformance to the testbed characteristics identified above before validations are conducted.

11.4.3.2.3 Plant Personnel

(1) Participants in the validation tests should be representative of actual plant personnel who will interact with the HSI, e.g., licensed operators rather than training or engineering personnel.

(2) To properly account for human variability, a sample of participants should be used. The sample should reflect the characteristics of the population from which the sample is drawn. Those characteristics that are expected to contribute to system performance variation should be specifically identified and the sampling process should ensure that variation along that dimension is included in the validation. Several factors that should be considered in determining representativeness include: license and qualifications, skill/experience, age, and general demographics.

(3) In selection of personnel, consideration should be given to the assembly of minimum and normal crew configurations, including shift supervisors, reactor operators, shift technical advisors, etc., that will participate in the tests.

(4) To prevent bias in the sample, the following participant characteristics and selection practices should be avoided:

- participants who are part of the design organization
- participants in prior evaluations
- participants who are selected for some specific characteristic, such as using crews that are identified as good or experienced.

11.4.3.2.4 Scenario Definition

(1) The operational conditions selected for inclusion in the validation tests should be developed in detail so they can be performed on a simulator. The following information should be defined to ensure that important performance dimensions are addressed and to allow scenarios to be accurately and consistently presented for repeated trials:

- description of the scenario and any pertinent "prior history" necessary for personnel to understand the state of the plant upon scenario start-up
- specific initial conditions (precise definition provided for plant functions, processes, systems, component conditions and performance parameters, e.g., similar to plant shift turnover)
- events (e.g., failures) to occur and their initiating conditions, e.g., time, parameter values, or events
- precise definition of workplace factors, such as environmental conditions
- task support requirements (e.g., procedures and technical specifications)
- taffing requirements
- communication requirements with remote personnel (e.g., load dispatcher via telephone)
- the precise specification of what, when and how data are to be collected and stored (including videotaping requirements, questionnaire and rating scale administrations)
- specific criteria for terminating the scenario.

(2) Scenarios should have appropriate task fidelity so that realistic task performance will be observed in the tests and so that test results can be generalized to actual operation of the real plant.

(3) When evaluating performance associated with operations remote from the main control room, the effects on crew performance due to potentially harsh environments (i.e., high radiation) should be realistically simulated (i.e., additional time to don protective clothing and access radiologically controlled areas).

11.4.3.2.5 Performance Measurement

The review criteria for performance measurement are divided into three sections. Section 11.4.3.2.5.1 addresses the measurement characteristics that effect the quality of the performance measures, Section 11.4.3.2.5.2 addresses the identification and selection of variables to represent measures of performance, and Section 11.4.3.2.5.3 addresses the development of performance criteria.

11.4.3.2.5.1 Measurement Characteristics

(1) *Performance Measurement Characteristics* - Performance measures should acceptably exhibit the following measurement characteristics to ensure that the measures are of good quality (it should be noted that some of the characteristics identified below may not apply to every performance measure):

- Construct Validity - A measure should accurately represents the aspect of performance to be measured.
- Diagnosticity - A measure should provide information that can be used to identify the cause of acceptable or unacceptable performance.
- Impartiality - A measure should be equally capable of reflecting good as well as bad performance.
- Objectivity - A measure should be based on phenomena that are easily observed.
- Reliability - A measure should be repeatable; i.e., if the same behavior is measured in exactly the same way under identical circumstances, the same measurement result should be obtained.
- Resolution - A measure should reflect the performance at an appropriate level of resolution, i.e., with sufficient detail to permit a meaningful analysis.
- Sensitivity - A measure's range (scale) and the frequency of measurement (how often data are collected) should be appropriate to the aspect of performance being assessed.
- Simplicity - A measure should be simple both from the standpoint of executing the tests and from the standpoint of communicating and comprehending the meaning of the measures.
- Unintrusiveness - A measure should not significantly alter the psychological or physical processes that are being investigated.

11.4.3.2.5.2 Performance Measure Selection

(1) A hierarchal set of performance measures should be used which includes measures of the performance of the plant and personnel (i.e., personnel tasks, situation awareness, cognitive workload, and anthropometric/physiological factors). Some of these measures could be used as "pass/fail" criteria for validation and the others to better understand personnel performance and to facilitate the analysis of performance errors. The applicant should identify which are in each category.

(2) *Plant Performance Measurement* - Plant performance measures representing functions, systems, components, and HSI use should be obtained.

(3) *Personnel Task Measurement* - For each specific scenario, the tasks that personnel are required to perform should be identified and assessed. Two types of personnel tasks should be measured: primary (e.g., start a pump), and secondary (e.g., access the pump status display). Primary tasks are those involved in performing the functional role of the operator to supervise the plant; i.e., monitoring, detection, situation assessment, response planning, and response implementation. Secondary tasks are those personnel must perform when interfacing with the plant, but which are not directed to the primary task, such as navigation and HSI configuration. This analysis should be used for the identification of potential errors of omission.

- Primary tasks should be assessed at a level of detail appropriate to the task demands. For example, for some simple scenarios, measuring the time to complete a task may be sufficient. For more complicated tasks, especially those that may be described as knowledge-based, it may be appropriate to perform a more fine-grained analysis such as identifying task components: seeking specific data, making decisions, taking actions, and obtaining feedback. Tasks that are important to successful integrated system performance and are knowledge-based should be measured in a more fine-grained approach.
- The measurement of secondary tasks should reflect the demands of the detailed HSI implementation, e.g., time to configure a workstation, navigate between displays, and manipulate displays (e.g., changing display type and setting scale).
- The tasks that are *actually* performed by personnel during simulated scenarios should be identified and quantified. (Note that the actual tasks may be somewhat different from those that should be performed). Analysis of tasks performed should be used for the identification of errors of commission.
- The measures used to quantify tasks should be chosen to reflect the important aspects of the task with respect to system performance, such as:
  - time
  - accuracy
  - frequency
  - errors (omission and commission)
  - amount achieved or accomplished
  - consumption or quantity used
  - subjective reports of participants
  - behavior categorization by observers

(3) *Situation Awareness* - Personnel situation awareness should be assessed. The approach to situation awareness measurement should reflect the current state-of-the-art.

(4) *Cognitive Workload* - Personnel workload should be assessed. The approach to workload measurement should reflect the current state-of-the-art.

(5) *Anthropometric and Physiological Factors* - Anthropometric and physiological factors include such concerns as visibility of indications, accessibility of control devices, and ease of control device manipulation that should be measured where appropriate. Attention should be focused on those aspects of the design that can only be addressed during testing of the integrated system, e.g., the ability of personnel to effectively use the various controls, displays, workstations, or consoles in an integrated manner.

11.4.3.2.5.3 Performance Criteria

(1) Criteria should be established for the performance measures used in the evaluations. The specific criteria that are used for decisions as to whether the design is validated or not should be specified and distinguished from those being used to better understand the results.

(2) The basis for criteria should be defined, e.g., requirement-referenced, benchmark referenced, normative referenced, and expert-judgement referenced.

11.4.3.2.6 Test Design

The review criteria for test design are divided into five sections. Section 11.4.3.2.6.1 addresses coupling crews and scenarios, Section 11.4.3.2.6.2 addresses test procedures, Section 11.4.3.2.6.3 addresses the training of test conductors, Section 11.4.3.2.6.4 addresses the training of test participants, and Section 11.4.3.2.6.5 addresses the conduct of pilot studies.

11.4.3.2.6.1 Coupling Crews and Scenarios

(1) *Scenario Assignment* - Important characteristics of scenarios should be balanced across crews. Random assignment of scenarios to crews is not recommended. The value of using random assignment to control bias is only effective when the number of crews is quite large. Instead, the validation team should attempt to provide each crew with a similar and representative range of scenarios.

(2) *Scenario Sequencing* - The order of presentation of scenario types to crews should be carefully balanced to ensure that the same types of scenarios are not always being presented in the same linear position, e.g., the easy scenarios are not always presented first.

11.4.3.2.6.2 Test Procedures

(1) Detailed, clear, and objective procedures should be available to govern the conduct of the tests. These procedures should include:

- The identification of which crews receive which scenarios and the order that the scenarios should be presented.
- Detailed and standardized instructions for briefing the participants. The type of instructions given to participants can affect their performance on a task. This source of bias can be minimized by developing standard instructions.
- Specific criteria for the conduct of specific scenarios, such as when to start and stop scenarios, when events such as faults are introduced, and other information discussed in Section 11.4.3.2.4, Scenario Definition.
- Scripted responses for test personnel who will be acting as plant personnel during test scenarios. To the greatest extent possible, responses to communications from operator participants to test personnel (serving as surrogate for personnel outside the control room personnel) should be prepared. There are limits to the ability to preplan communications since personnel may ask questions or make requests that were not anticipated. However, efforts should be made to detail what information personnel outside the control room can provide, and script the responses to likely questions.

- Guidance on when and how to interact with participants when simulator or testing difficulties occur. Even when a high-fidelity simulator is used, the participants may encounter artifacts of the test environment that detract from the performance for tasks that are the focus of the evaluation. Guidance should be available to the test conductors to help resolve such conditions.
- Instructions regarding when and how to collect and store data. These instructions should identify which data are to be recorded by:
  - simulation computers
  - special purpose data collection devices (such as situation awareness data collection, workload measurement, or physiological measures)
  - video recorders (locations and views)
  - test personnel (such as observation checklists)
  - subjective rating scales and questionnaires.
- Procedures for documentation, i.e., identifying and maintaining test record files including crew and scenario details, data collected, and test conductor logs. These instructions should detail the types of information that should be logged (e.g., when tests were performed, deviations from test procedures, and any unusual events that may be of importance to understanding how a test was run or interpreting test results) and when it should be recorded.

(2) Where possible, test procedures should minimize the opportunity of tester expectancy bias or participant response bias.

11.4.3.2.6.3 Test Personnel Training

(1) Test administration personnel should receive training on:

- the use and importance of test procedures
- experimenter bias and the types of errors that may be introduced into test data through the failure of test conductors to accurately follow test procedures or interact properly with participants
- the importance of accurately documenting problems that arise in the course of testing, even if due to test conductor oversight or error.

11.4.3.2.6.4 Participant Training

(1) Participant training should be of high fidelity; i.e., highly similar to that which plant personnel will receive in an actual plant. The participants should be trained to ensure that their knowledge of plant design, plant operations, and use of the HSIs and procedures is representative of experienced plant personnel. Participants should not be trained specifically to perform the validation scenarios.

(2) Participants should be trained to near asymptotic performance (i.e., stable, not significantly changing from trial to trial) and tested prior to conducting actual validation trials. Performance criteria should be similar to that which will be applied to actual plant personnel.

11.4.3.2.6.5 Pilot Testing

(1) A pilot study should be conducted prior to conducting the integrated validation tests to provide an opportunity to assess the adequacy of the test design, performance measures, and data collection methods.

(2) If possible, participants who will operate the integrated system in the validation tests should not be used in the pilot study. If the pilot study must be conducted using the validation test participants, then:

- the scenarios used for the pilot study should be different from those used in the validation tests, and
- care should be given to ensure that the participants do not become so familiar with the data collection process that it may result in response bias.

11.4.3.2.7 Data Analysis and Interpretation

(1) Validation test data should be analyzed through a combination of quantitative and qualitative methods. The relationship between observed performance data and the established performance criteria should be clearly established and justified based upon the analyses performed.

(2) For performance measures used as pass/fail indicators, failed indicators must be resolved before the design can be validated. Where performance does not meet criteria for the other performance measures, the results should be evaluated using the HED evaluation process.

(3) The degree of convergent validity should be evaluated, i.e., the convergence or consistency of the measures of performance.

(4) The data analyses should be independently verified for correctness of analysis.

(5) The inference from observed performance to estimated real-world performance should allow for margin of error; i.e., some allowance should be made to reflect the fact that actual performance may be slightly more variable than observed validation test performance.

11.4.3.2.8 Validation Conclusions

(1) The statistical and logical bases for determining that performance of the integrated system is and will be acceptable should be clearly documented.

(2) Validation limitations should be considered in terms of identifying their possible effects on validation conclusions and impact on design implementation. These include:

- aspects of the tests that were not well controlled
- potential differences between the test situation and actual operations, such as absence of productivity-safety conflicts
- potential differences between the validated design and plant as built (if validation is directed to an actual plant under construction where such information is available or a new design using validation results of a predecessor)

11.4.4 Human Engineering Discrepancy Resolution

HED Resolution is an activity that can be performed iteratively with V&V. That is, the applicant may integrate these activities so that issues identified during a V&V activity are addressed and resolved prior to conducting other V&V activities.

The purpose of the staff's review of the HED Resolution is to ensure that the applicant has adequately completed the following tasks:

- evaluated HEDs to determine the need for their correction
- identified design solutions to address significant HEDs
- verified the implementation of the design solutions resolving HEDs.

HEDs should not considered in isolation and, to the extent possible, their potential interactions should be considered when developing and implementing solutions. For example, if the HSI for a single plant system is associated with many HEDs, then the set of design solutions should be coordinated to enhance overall performance and avoid incompatibilities between individual solutions. Approaches that develop design solutions to some HEDs before all have been identified from a particular verification or validation activity are acceptable provided that the potential interactions between HEDs are specifically considered prior to implementing the design solutions.

11.4.4.1 Human Engineering Discrepancy Resolution Review Objective

The objectives of the review are to ensure that:

- The applicant's HED evaluation acceptably prioritizes HEDs in terms of their need for improvement. (An HED evaluation is required only if the applicant does not plan to correct all HEDs. If all HEDs are to be corrected, design improvements should be identified, see Review Criteria 4 to 6 below).
- The applicant develops design solutions and a realistic schedule for implementation to address those HEDs selected for correction.

11.4.4.2 Human Engineering Discrepancy Resolution Review Criteria

(1) *HED Justification* - Discrepancies could be acceptable within the context of the fully integrated design. If sufficient justification exists, a deviation from the guidelines may not constitute an HED. The technical basis for such a determination could include an analysis of recent literature or current practices, tradeoff studies, or design engineering evaluations and data. Unjustified discrepancies should be identified as HEDs to be addressed by the HED resolution.

(2) *HED Analysis* - The following should be included in the HED evaluations:

- Plant system - the potential effects of all HEDs relevant to a single plant system should be evaluated. The potential effects of these HEDs on plant safety and personnel performance should be determined, in part, by the safety significance of the plant system(s), their effect on SAR accident analyses, and their relationship to risk significant sequences in the plant PRA.
- HED scope

- Global features HEDs - these are HEDs that relate to configurational and environmental aspects of the design such as lighting, ventilation, and traffic flow. They relate to general human performance issues.
- Standardized features HEDs - these are HEDs that relate to design features that are governed by the applicant's design guidelines used across various controls and displays of the HSI (e.g., display screen organization and conventions for format, coding, and labeling). Because a single guideline may be used across many aspects of the design, a single HED could be applicable to many personnel tasks and plant systems.
- Detailed features HEDs - these are HEDs that relate to design features that are not standardized, thus there generality has to be assessed.
- Other - this subcategory specifically pertains to HEDs identified from integrated system validation that cannot be easily assigned to any of the three preceding categories.

- Individual HSI or procedure - HEDs should be analyzed with respect to individual HSIs and procedures. The potential effects of these HEDs on plant safety and personnel performance are determined, in part, by the safety significance of the plant system(s) that are related to the particular component.
- Personnel function - HEDs should be analyzed with respect to individual personnel functions. The potential effects of these HEDs is determined, in part, by the importance of the personnel function to plant safety (e.g., consequences of failure) and their cumulative effect on personnel performance (e.g., degree of impairment and types of potential errors).

HEDs should also be analyzed with respect to the cumulative effects of multiple HEDs on plant safety and personnel performance. While an individual HED might not be considered sufficiently severe to require correction, the combined effect of several HEDs upon the single aspect of the design could have significant consequences to plant safety and, therefore, necessitate corrective action. Likewise, when a single plant system is associated with multiple HEDs that affect a number of HSI components, then their possible combined effect on the operation of that plant system should be considered

In addition to addressing the specific HEDs, the analysis should treat the HEDs as indications of potentially broader problems. For example, identifying multiple HEDs associated with one particular aspect of the HSI design, such as the remote shutdown panel, could also indicate that there are other problems with that aspect of the design, such as inconsistent use of procedures and standards. In some cases, the evaluation of HEDs could warrant further review in the identified areas of concern.

(3) *HED Prioritization* - Identification of HEDs for correction should be based upon a systematic evaluation, such as that illustrated in Figure 11.2. Priority 1 HEDs should be those with direct safety consequences and those with indirect or potential safety consequences. HEDs with significant safety consequences are those that affect personnel performance where the consequences of error could reduce the margin of plant safety below an acceptable level, as indicated by such conditions as violations of Technical Specification safety limits, operating limits, or limiting conditions for operations. They include violations of personnel information requirements or HFE guidelines for personnel tasks that are related to plant safety. These could include the following:

- are required by personnel tasks but are not provided by the HSI
- do not satisfy all personnel information requirements (e.g., information not presented with the proper range or precision)
- contain violations of HFE guidelines that are likely to lead to errors that would prevent personnel from performing the task.

HEDs with indirect safety consequences include violations of HFE guidelines that would seriously affect the ability of personnel to perform the task. The severity of an HFE guideline violation should be assessed in terms of the degree to which it contributes to human performance problems, such as workload and information overload.

Priority 2 HEDs should be those that do not have significant safety consequences, but do have potential consequences to plant performance/operability, non-safety-related personnel performance/efficiency, or other factors affecting overall plant operability. These include violations of personnel information requirements and HFE guidelines for tasks associated with plant productivity, availability, and protection of investment. These HEDs should be considered for correction.

The remaining HEDs are those that do not satisfy the criteria associated with the first and second priorities. Resolution of these HEDs is not an NRC safety concern but may be resolved at the discretion of the applicant.

(4) *HED Evaluation Documentation* - Each HED should be fully documented including assessment category (priority for correction), associated plant system, associated personnel function, and associated HSI or procedure. The documentation should clearly show whether the HED was dismissed or identified as needing design modification, and the basis for this determination in terms of consequence to plant safety or operation should be clearly described.

(5) *Development of Design Solutions* - Design solutions to correct HEDs should be identified. The design solutions should be consistent with system and personnel requirements identified in the Preparatory Analysis (i.e., Operating Experience Review, Function and Task Analysis, and HSI Characterization).

Inter-relationships of individual HEDs should be evaluated. For example, if a single HSI component is associated with multiple HEDs, then design solutions should be considered to address these HEDs together. If a single plant system is associated with multiple HSI components that are associated with HEDs, then the design of the individual solutions should be coordinated so that their combined effect enhances rather than detracts from that system's operation.

(6) *Design Solution Evaluation* - Designs should be evaluated by repeating the appropriate analyses of the verification and validation. For example, the HSI Task Support Verification should be conducted to ensure that the design satisfies personnel task requirements. Portions of the HFE design verification analysis should be conducted to ensure that the design is consistent with HFE guidelines, and integrated system validation could be conducted to evaluate its usability. When the problems identified by an HED cannot be fully corrected, justification should be given.

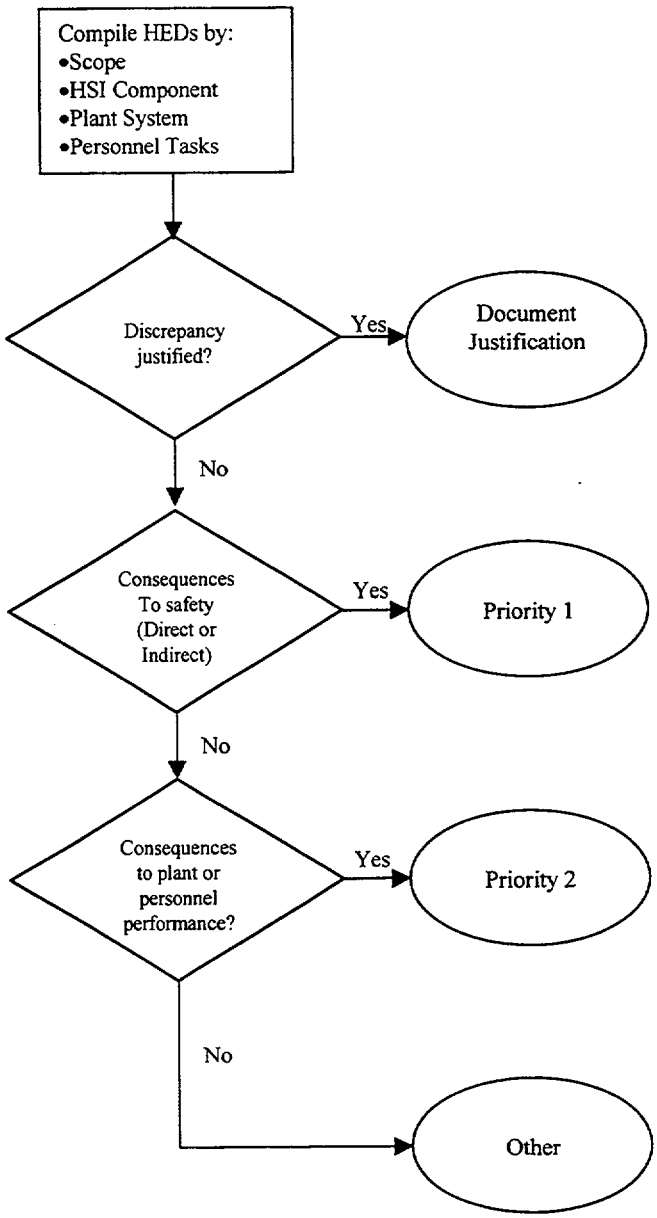

Figure 11.2 The HED Evaluation Process

(7) *Design Modification* - There should be an implementation schedule for activities associated with installing, testing, and HFE evaluation of the design solutions. All design solutions for Priority 1 HEDs should be scheduled for prompt implementation. The schedule should be developed to minimize demands and disruptions for personnel. For operating plants, the schedule should distinguish between solutions that can be implemented without interfering with the operation of the plant, and improvements that can only be made when the plant is not operating. Installing large groups of design solutions at discrete intervals should be considered to avoid subjecting

operating crews to a continually changing HSI. Procedures should be established to ensure that information related to the design of the HSI such as plant procedures, drawings, and training programs is updated to reflect the changes.

11.5 Sources of Additional Information

The following documents may be used as guidance (per Section 1.2.2):

ANSI/AIAA G-035-1992: *Guide to Human Performance Measurements* (American National Standards Institute, 1993).

IEC 1771: *Nuclear Power Plants Main Control Rooms--Verification and Validation of Design* (International Electrotechnical Commission, 1995).

IEEE Std. 845-1999: *IEEE Guide to the Evaluation of Human-System Performance in Nuclear Power Generating Stations*, 1999 (Institute of Electrical and Electronics Engineers, 1999).

NUREG/CR-6393: *Integrated System Validation: Methodology and Review Criteria* (O'Hara et al., 1997)

NUREG-0700: *Human-System Interface Design Review Guidelines* (NRC, 2002).

Regulatory Guide 1.33: *Quality Assurance Program Requirements* (NRC, 1978).

In addition, documents listed for the following elements can be used to support V&V activities:

- HSI Design
- Procedure Development
- Training Program Development

12 DESIGN IMPLEMENTATION

12.1 Background

This section addresses the implementation of the HFE aspects of the plant design for both new plants and plant modifications. For a new plant, the implementation phase is well defined and carefully monitored by start-up procedures and testing; implementation of plant modifications is more complex.

Plant modifications can effect personnel in various ways. Changes to systems and components can impact the role of personnel and the way their tasks are performed. Often such plant modifications lead to changes in HSIs, procedures, and training as well. Modifications can also address the HFE aspects of the plant even though the plant's systems and components are not changed.

There are many different ways that modifications can be implemented. Some of these approaches and their advantages and disadvantages are illustrated in Table 12-1. The HFE considerations for each are somewhat unique.

For both new and modified designs, it is important to determine that the design that is implemented (i.e., the "as-built" design) accurately reflects the verified and validated design.

12.2 Objective

The objective of this review is to ensure that:

- the applicant's implementation of plant changes considers the effect on personnel performance and provides the necessary support to ensure safe operations
- the applicant's as-built design conforms to the verified and validated design that resulted from the HFE design process.

12.3 Applicant Submittals

As per Section 1.2.1, item (3) Applicant Submittals, the applicant should provide for staff review an *implementation plan* for design implementation. Upon completion of the applicant's efforts, a *results summary report* should be submitted so that the staff can review the applicant's design implementation using the criteria provided in Section 12.4 below.

12.4 Review Criteria

The first five sections of review criteria are for the review of plant modifications only. Section 12.4.6, Final Plant HFE Design Verification, applies to both new and modified plant designs.

12.4.1 General Criteria

(1) The applicant should ensure that the reactor fuel is safely monitored during the shutdown time period while the physical modifications are being implemented in the control room.

(2) Operations and maintenance crews should be fully trained and qualified to operate and maintain the plant with respect to all modifications prior to starting-up with the new systems and HSIs in place.

Table 12-1 Typical Advantages and Disadvantages of Different Methods of Modernization Program Implementation

Many Small Modifications

Advantages

- Minimal disruption to operations.

Disadvantages

- Risk of unexpectedly affecting plant operation (such as through spurious actuation)
- Likelihood for inconsistency and lack of standardization of HSIs as many new and different system are separately added to the control room. As a result, operators are unsure precisely how each HSI functions.
- Overlapping functionality - many HSIs do the same things and provide the same functions.
- Training on small modifications may be lacking, so personnel do not use the new systems effectively or at all.

Large Modifications During a Single Outage

Advantages

- The potential for negative effects on crew performance of interim configurations is eliminated, since all the changes are made at once.
- Cost savings in comparison to multiple outages because (1) interim periods do not have to be analyzed, (2) procedures and do not have to be temporarily modified, and (3) crews do not have to be trained for temporary HSIs.

Disadvantages

- Significant changes to the plant and HSIs can have significant effects on the way crews operate the plant.
- Cost impact of loss of production during the extended outage.

Large Modifications During Multiple Outages

Advantages

- Drastic changes to operations can be minimized by breaking up modifications into smaller logical units.
- Plant staff can gain experience with non-safety (less critical) systems so when safety (critical) systems are modified the plant staff are in a more knowledgeable position.

Disadvantages

- Task performance can be hampered if the interim configuration requires parts of a task to be performed using the old HSI and other parts with the new HSI.
- Interim stages between old and new systems can be especially error prone if not fully addressed in analyses and by training and procedure modifications.

Both Old and New Equipment are Left in Place

Advantages

- Any problems with the new system can be identified and resolved while the old HSIs are in place and can act as backups.
- Operators can become familiar with the new HSIs while the old HSIs are still available.
- Old HSIs are available in an emergency (research has shown that operators often prefer the familiar HSIs when in stressful conditions)

Disadvantages

- HSI conflicts between old and new systems (such as different values for the same process parameter) Control room clutter and potential distraction of two sets of HSIs

New Non-Functional HSIs in Place in Parallel with Old Functional HSIs

Advantages

- Operators can become familiar with the new HSIs while the old HSIs are still available.

Disadvantages

- Control room clutter and potential distraction of two sets of HSIs
- Crew may use the new HSIs inadvertently or because they do not realize that the HSIs are non-functional.

(3) Modifications in plant procedures and training should reflect changes in plant systems, crew roles and responsibilities, HSIs, and procedures resulting from the new systems and HSIs should be in place prior to startup.

(4) The applicant should have a plan in place to monitor the initial phase of startup to ensure that:

- operational and maintenance problems that arise with personnel interactions with the new systems, HSIs, and procedures are identified and addressed
- personnel are sufficiently familiar with the new systems, HSIs, and procedures to support safe operations and maintenance.
- any negative transfer of training from the old removed HSIs to the corresponding new HSIs is identified and corrected
- no new problems are created based on coordination of tasks between remaining old HSIs and new HSIs
- no unanticipated negative effects on crew interaction and teamwork arise

12.4.2 Modernization Programs Consisting of Many Small Modifications

(1) Each modification should follow a HFE program that ensures standardization and consistency (1) between old and new equipment and (2) across the new systems being implemented.

(2) The applicant should ensure that new modifications fulfill a clear operational need and do not interfere with existing systems. For example, the auditory alerts in a new HSI should not distract operators from addressing more important alarms in the main system.

12.4.3 Modernization Programs Consisting of Large Modifications During Multiple Outages

(1) The interim configurations should be carefully defined and evaluated to ensure that they are acceptable both from an engineering and operations perspective and meet regulatory requirements. Evaluations should include:

- PRA
- Safety Analysis Report (SAR)
- Technical specifications
- Defense-in-depth

(3) Task analysis should be performed for each interim configuration to ensure that the task demands the are unique to interim configurations are known.

(4) HRA should address any unique tasks that may impact risk or any changes to existing tasks due to the interim configuration.

(5) The HSIs needed to perform important tasks should be consistent and standardized. Task performance should not require personnel to use both old and new HSIs for different aspects of the same task. If the underlying I&C modifications necessitate this situation, consideration should be given to creating temporary HSIs specifically designed for such tasks.

(6) Procedures should be developed for temporary configurations of systems and HSIs that are used by personnel when the plant is not shutdown.

(7) Training should be developed for temporary configurations of systems, HSIs, and procedures that are used by personnel when the plant is not shutdown.

(8) Verification and Validation

- HFE Design Verification - Temporary configurations of the systems, HSIs, and procedures, which may be used by operations and maintenance personnel when the plant is not shutdown, should be reviewed to ensure that their design is consistent with the principles of good HFE design.
- HSI Task-Support Verification - Temporary configurations of the systems, HSIs, and procedures, which may be used by operations and maintenance personnel when the plant is not shutdown, should be reviewed to ensure that their design supports the tasks that will be performed. For example, if a temporary configuration of plant systems introduces special monitoring requirements, then the HSIs should provide the necessary information.
- Validation should be performed on interim configurations if warranted by the risk-significance of the crew tasks affected by the temporary configuration.

12.4.4 Modernization Programs Where Both Old and New Equipment are Left in Place

(1) The potential for negative effects on personnel performance due to control room or HSI clutter arising from having both old and new HSIs available in parallel should be evaluated. Where safety concerns are identified, appropriate measures should be taken to improve the HSIs.

(2) The potential for negative effects on personnel performance due to the simultaneous presence of parallel alarm systems should be evaluated. Where safety concerns are identified, appropriate measures should be taken to improve the HSIs.

(3) The potential should be evaluated for negative effects on personnel performance due to the differences between information from old and new systems for the same parameter or equipment. Where safety concerns are identified, appropriate measures should be taken to improve the HSIs.

(4) An evaluation should be performed to identify any safety concerns from providing controls from two different HSIs. Where a concern is identified, appropriate measures should be developed to prevent the concern. For example, a switch may be added to select which HSI controls the equipment thus preventing simultaneous control inputs.

12.4.5 Modernization Programs Where New Non-Functional HSIs are in Place in Parallel with Old Functional HSIs

(1) The potential for negative effects on personnel performance due to control room or HSI clutter arising from having both old and new HSIs available in parallel should be evaluated. Where safety concerns are identified, appropriate measures should be taken to improve the HSIs.

(2) The non-functional state of the HSIs should be clearly indicated.

12.4.6 Final Plant HFE Design Verification

(1) Aspects of the design that were not addressed in V&V should be evaluated using an appropriate V&V method. Aspects of the design addressed by this criterion may include design characteristics such as new or modified displays for plant-specific design features and features that cannot be evaluated in a simulator such as CR lighting and noise.

(2) The final (as-built in the plant) HSIs, procedures, and training should be compared with the detailed design description to verify that they conform to the design that resulted from the HFE design process and V&V activities. Any identified discrepancies should be corrected or justified.

(3) All HFE-related issues documented in the issue tracking system should be verified as adequately addressed.

12.5 Sources of Additional Information

The following document may be used for additional information (per Section 1.2.2):

10 CFR Part 50.59: *U.S. Code of Federal Regulations*, Part 50.59 *"Changes, Tests, and Experiments*," Title 10, "Energy."

IEC 62096 *Nuclear Power Plants - Instrumentation and Control: Guidance for the Decision on Modernization* (IEC, 2001).

NEI 96-01, Rev. 1: *Guidelines for 10 CFR 50.59 Implementation* (Nuclear Energy Institute, 2000).

13 HUMAN PERFORMANCE MONITORING

13.1 Background

A human performance monitoring strategy will help to ensure that the confidence developed by the completion of the integrated system validation is maintained over time. There is no intent to periodically repeat the full integrated system validation; however, there should be sufficient evidence to provide reasonable confidence that plant personnel have maintained the skills necessary to accomplish the assumed actions.

13.2 Objective

The objective of this review is to assure that the applicant has prepared a human performance monitoring strategy for ensuring that no significant safety degradation occurs because of any changes that are made in the plant and to provide adequate assurance that the conclusions that have been drawn from the evaluation remain valid over time. The applicant may incorporate this monitoring strategy into their problem identification and corrective action program

13.3 Applicant Submittals

Submittals for the staff's review of an applicant's human performance monitoring program should be made on a case-by-case basis.

13.4 Review Criteria

(1) The scope of the performance monitoring strategy should provide assurance that:

- The design can be effectively used by personnel, including within the control room and between the control room and local control stations and support centers.
- Changes made to the HSIs, procedures, and training do not have adverse effects on personnel performance, e.g., a change interferes with previously trained skills.
- Human actions can be accomplished within time and performance criteria.
- The acceptable level of performance established during the integrated system validation is maintained.

(2) A human performance monitoring strategy should be developed and documented. The strategy should be capable of trending human performance after the changes have been implemented to demonstrate that performance is consistent with that assumed in the various analyses that were conducted to justify the change. Applicants may integrate, or coordinate, their performance monitoring for risk-informed changes with existing programs for monitoring personnel performance, such as the licensed operator training program and the corrective action program. If a plant change requires monitoring of actions that are not included in existing training programs, it may be advantageous to adjust the existing training program rather than to develop additional monitoring programs for risk-informed purposes.

(3) The program should be structured such that

- human actions are monitored commensurate with their safety importance
- feedback of information and corrective actions are accomplished in a timely manner
- degradation in performance can be detected and corrected before plant safety is compromised (e.g., by use of the plant simulator during periodic training exercises)

(4) Plant or personnel performance under actual design conditions may not be readily measurable. When actual conditions cannot be simulated, monitored, or measured, the available information that most closely approximates performance data in actual conditions should be used.

(5) As part of the monitoring program, it is important that provisions for specific cause determination, trending of performance degradation and failures, and corrective actions be included. The cause determination should identify the cause of the failure or degraded performance to the extent that corrective action can be identified that would preclude the problem or provide adequate assurance that it is anticipated prior to becoming a safety concern. The program should address failure significance, the circumstances surrounding the failure or degraded performance, the characteristics of the failure, and whether the failure is isolated or has generic or common cause implications. The monitoring program should identify and establish any corrective actions necessary to preclude the recurrence of unacceptable failures or degraded performance.

13.5 Sources of Additional Information

The following documents may be used for additional information (per Section 1.2.2):

CN Number 02-001: *NRC Inspection Manual: Chapter 2515, Light-Water Reactor Inspection Program - Operations Phase* (NRC, 2002).

CN Number 01-015: *NRC Inspection Manual: Chapter 0609, Significance Determination Process* (NRC, 2001).

IP 71715: *Sustained Control Room and Plant Observation.* (NRC, periodically updated).

NUREG-1649: *Reactor Oversight Process* (NRC, 2000).

Regulatory Guide 1.174: *An approach for using probabilistic risk assessment in risk-informed decisions on plant-specific changes to the licensing basis* (NRC, 1998).

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GLOSSARY

Advanced control room - A control room that is primarily based on digital technology. It typically provide the primary operator interaction with the plant via computer-based interfaces, such as video display units. This is in contrast to "conventional" control rooms, which provide the primary operator interaction with the plant via analog interfaces, such as gauges.

Applicant - An organization such as a nuclear plant vendor or utility that is applying to the U.S. Nuclear Regulatory Commission for design certification or plant licensing.

Bias - Bias is an aspect of an evaluation methodology which systematically modifies performance or the interpretation of performance.

Component - The meaning of the word component depends on its context. In context of the entire plant, it is an individual piece of equipment such as a pump, valve, or vessel; usually part of a plant system. In a human-system interface context, a component is one part of a larger unit, such as one meter in a control board. In a maintenance context, a component is a subdivision of a unit of equipment that can be treated as an object by the maintainer, but which can be further broken down into parts. A mounting board together with its mounted parts is an example of a component.

Confound - The systematic coupling of one aspect of the test with another or with an extraneous variable. Confounding makes important relationships ambiguous.

Construct validity - The extent to which a selected performance measure accurately represents the aspect of performance to be measured.

Convergent validity - The degree to which consistent results are observed across different review, evaluation, or measurement techniques.

Function - (1) A software supported capability provided to a user to aid in performing a task. (2) A process or activity that is required to achieve a desired goal; see, e.g., "Safety function."

Function allocation -The process of assigning responsibility for function accomplishment to human or machine resources, or to a combination of human and machine resources.

Functional requirements analysis - The examination of system goals to determine what functions are needed to achieve them.

Functional requirements specification - A specification which identifies the functions and characteristics that the human-system interface and its components accomplish or satisfy.

Human action - See "risk-important human actions."

Human-centered design goals - Human factors engineering design goals that address the cognitive and physical support of personnel performance.

Human factors - A body of scientific facts about human characteristics. The term covers all biomedical, psychological, and psycho-social considerations; it includes, but is not limited to, principles and

applications in the areas of human factors engineering, personnel selection, training, job performance aids, and human performance evaluation (see "Human factors engineering").

Human factors engineering (HFE) - The application of knowledge about human capabilities and limitations to plant, system, and equipment design. HFE ensures that the plant, system, or equipment design, human tasks, and work environment are compatible with the sensory, perceptual, cognitive, and physical attributes of the personnel who operate, maintain, and support it (see "Human factors").

Human-system interfaces (HSIs) - A human-system interface (HSI) is that part of the system through which personnel interact to perform their functions and tasks. In this document, "system" refers to a nuclear power plant. Major HSIs include alarms, information displays, controls, and procedures. Use of HSIs can be influenced directly by factors such as, (1) the organization of HSIs into workstations (e.g., consoles and panels); (2) the arrangement of workstations and supporting equipment into facilities such as a main control room, remote shutdown station, local control station, technical support center, and emergency operations facility; and (3) the environmental conditions in which the HSIs are used, including temperature, humidity, ventilation, illumination, and noise. HSI use can also be affected indirectly by other aspects of plant design and operation such as crew training, shift schedules, work practices, and management and organizational factors.

Integrated system validation - Integrated System Validation is an evaluation using performance-based tests to determine whether an integrated system design (i.e., hardware, software, and personnel elements) meets performance requirements and acceptably supports safe operation of the plant.

Local control station (LCS) - An operator interface related to process control that is not located in the main control room. This includes multifunction panels, as well as single-function LCSs such as controls (e.g., valves, switches, and breakers) and displays (e.g., meters) that are operated or consulted during normal, abnormal, or emergency operations.

Mockup - A static representation of an human-system interface (see "Simulator" and "Prototype").

Modification - Any type of change or modernization made to HSI components or plant systems that may influence personnel performance.

Operating experience review - A review of relevant history from the plant's on-going collection, analysis, and documentation of operating experiences and from interviews with plant staff.

Performance-based test - Tests that involve the measurement of behavior of personnel, the human-system interface, or aspects of the plant to address design issues and design acceptability.

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.

Personal safety - Relates to the prevention of individual accidents and injuries of the type regulated by the Occupational Safety and Health Administration.

Plant - The operating unit of a nuclear power station including the nuclear steam-supply system, the turbine, electrical generator, and all associated systems and components. In the case of a multi-unit plant, the term plant refers to all systems and processes associated with the unit's ability to produce electrical power, even though some systems or portions of systems may be shared with the other units.

Plant safety - Also called "safe operation of the plant." A general term used herein to denote the technical safety objective 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 ensure 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 ensure that the likelihood of severe accidents with serious radiological consequences is extremely small."

Primary tasks - Those tasks performed by the operator to supervise the plant; i.e., monitoring, detection, situation assessment, response planning, and response implementation.

Procedures - Written instructions providing guidance to plant personnel for operating and maintaining the plant and for handling disturbances and emergency conditions.

Prototype - A dynamic representation of a human-system interface that is not linked to a process model or simulator. A model of an interface which includes the functions and capabilities expected in the final system, though not in a finished form. (See "Simulator" and "Mockup").

Risk-important human actions - Actions that are performed by plant personnel to ensure 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 ensure that predefined risk criteria are met. From a relative standpoint, the risk important actions may be defined as those with the greatest risk in comparison to all human actions. The identification can be done quantitatively from risk analysis and qualitatively from various criteria such as task performance concerns based on the consideration of performance shaping factors.

Safety - See "Personal safety," "Plant safety," "Safety evaluation," "Safety function," "Safety issue," and "Safety-related."

Safety evaluation - The NRC process of reviewing an aspect of an NPP to ensure that it meets requirements and that it will perform as needed to reliably ensure plant safety.

Safety function - Safety functions are those functions that serve to ensure higher-level objectives and are often defined in terms of a boundary or entity that is important to plant integrity and the prevention of the release of radioactive materials. A typical safety function is "reactivity control." A high-level objective, such as preventing the release of radioactive material to the environment, is one that designers strive to achieve through the design of the plant and that plant operators strive to achieve through proper operation of the plant. The function is often described without reference to specific plant systems and components or the level of human and machine intervention that is needed to carry out this action. Functions are often accomplished through some combination of lower-level functions, such as "reactor trip." The process of manipulating lower-level functions to satisfy a higher-level function is defined here as a control function. During function allocation the control function is assigned to human and machine elements.

Safety issue - An item identified during plant design, operation, or review that has the potential to affect the safe operation of the plant.

Safety-related - A term applied to those NPP structures, systems, and components (SSCs) that prevent or mitigate the consequences of postulated accidents that could cause undue risk to the health and safety of the public (see Appendix B to Part 50 of Title 10 of the U.S. Code of Federal Regulations). These are the SSCs on which the design-basis analyses of the safety analysis report are performed. They also should be part of a full quality assurance program in accordance with Appendix B of that document.

Secondary tasks - Those tasks that operators perform when interacting with the human-system interface that are not directed to the primary task. Secondary tasks may include: navigating through and paging displays, searching for data, choosing between multiple ways of accomplishing the same task, and making decisions regarding how to configure the interface.

Simulator - A facility that physically represents the human-system interface configuration and that dynamically represents the operating characteristics and responses of the plant in real time. (see "Mockup" and "Prototype").

Situation awareness - The relationship between the operator's *understanding* of the plant's condition and its actual condition at any given time.

State-of-the-art human factors principles - Those principles currently accepted by human factors practitioners. "Current" is defined with reference to the time at which a program management or implementation plan is prepared. "Accepted" is defined as a practice, method, or guide that (1) is documented in the human factors literature within a standard or guidance document that has undergone a peer-review process or (2) can be justified through scientific research and/or industry practices.

Style guide - A document that contains guidelines that have been tailored so they describe the implementation of HFE guidance to a specific design, such as for a specific plant control room.

Subsidiary tasks - Tasks used for workload assessment. These tasks are given to operators to perform while they are performing primary and secondary tasks. Their performance is theoretically tied to cognitive workload through measurement of spare mental capacity. Better performance on subsidiary tasks reflects more spare mental capacity and, therefore, lower primary/secondary task workload.

System - An integrated collection of plant components and control elements that operate alone or with other plant systems to perform a function.

Task - A group of activities that have a common purpose, often occurring in close temporal proximity.

Task Analysis - A method for describing what plant personnel must do to achieve the purposes or goal of their tasks. The description can be in terms of cognitive activities, actions, and supporting equipment.

Testbed - The representation of the human-system interface and the process model used in testing.

Top-down review - A review approach that follows top - down design. In a top down design approach, the design starts at the "top" with high-level plant mission goals that are broken down into functions that

are allocated to human and system resources and are further broken down into tasks performed to accomplish function assignments. Tasks are arranged into meaningful jobs and the human-system interface is designed to best support job task performance. The detailed design is the "bottom" of the top-down design process.

Trade-off evaluations - Comparisons performed between design options based on aspects of human performance that are important to task performance.

Validation - (see "Integrated system validation")

Validity - The characteristics of the methods and tools used in the validation process.

Verification - The process by which the design is evaluated to determine whether it acceptably satisfies personnel task needs and HFE design guidance.

Vigilance - The degree to which an operator is alert.

Workload - The physical and cognitive demands placed on plant personnel.

APPENDIX
HFE DESIGN TEAM COMPOSITION

The term "HFE design team" is used in a generic sense to refer to the personnel who are responsible for HFE within the scope of this report. There is no intent to prescribe any particular organizational structure for an applicant, nor is it assumed that HFE is the responsibility of a single organization or that there is necessarily an organizational unit called the HFE design team.

The following is a listing of the areas of expertise for the HFE design team. Associated with each area of expertise is a listing of minimum qualifications and descriptions of typical contributions to the HFE design and implementation process. The descriptions of typical contributions are provided as examples to further describe the potential value of the various areas of expertise to the HFE design and implementation process. This is not intended to define the total role of each area of expertise.

(1) **Technical Project Management**

- Minimum qualifications:
  - Bachelor's degree
  - 5 years of experience in nuclear power plant design or operations
  - 3 years of management experience
- Typical contributions:
  - develop and maintain the schedule for the HFE design process
  - provide a central point of contact for management of the HFE design and implementation process

(2) **Systems Engineering**

- Minimum qualifications:
  - Bachelor of Science degree
  - 4 years of cumulative experience in at least three of the following areas of systems engineering; design, development, integration, operation, and test and evaluation
- Typical contributions:
  - provide knowledge of the purpose, operating characteristics, and technical specifications of major plant systems
  - provide input to HFE analyses, especially function analysis and task analysis
  - participate in the development of procedures and scenarios for task analysis, validation, and other analyses

(3) **Nuclear Engineering**

- Minimum qualifications:
  - Bachelor of Science degree
  - 4 years of nuclear design, development, test, or operations experience.

- Typical contributions:
  - provide knowledge of the processes involved in reactivity control and power generation
  - provide input to HFE analyses, especially function analysis and task analysis
  - participate in the development of scenarios for task analysis, validation, and other analyses

(4) **Instrumentation and Control (I&C) Engineering**

- Minimum qualifications:
  - Bachelor of Science degree
  - 4 years of experience in design of hardware and software aspects of process control systems
  - experience in at least one of the following areas of I&C engineering: development, power plant operations, and test and evaluation
  - familiarity with the theory and practice of software quality assurance and control
- Typical contributions:
  - provide detailed knowledge of the human-system interface (HSI) design, including control and display hardware selection, design, functionality, and installation
  - provide knowledge of information display design, content, and functionality
  - participate in the design, development, test, and evaluation of the HSIs
  - participate in the development of scenarios for human reliability analysis (HRA), validation, and other analyses involving failures of the HSI data processing systems
  - provide input to software quality assurance programs

(5) **Architect Engineering**

- Minimum qualifications:
  - Bachelor of Science degree
  - 4 years of experience in design of power plant control rooms
- Typical contributions:
  - provide knowledge of the overall structure of the plant including performance requirements, design constraints, and design characteristics of the following: containment building, control room, remote shutdown area, and local control stations
  - provide knowledge of the configuration of plant components within the plant
  - provide input to plant analyses, especially function analysis, task analysis, and the development of scenarios for task analysis and validation

(6) **Human Factors Engineering**

- Minimum qualifications:
  - Bachelor's degree in Human Factors Engineering, Engineering Psychology, or related science
  - 4 years of cumulative experience related to the human factors aspects of human-computer interfaces. Qualifying experience should include at least the following activities within the context of large-scale human-machine systems (e.g., process control): design, development, and test and evaluation
  - 4 years of cumulative experience related to the human factors aspects of workplace design. Qualifying experience should include at least two of the following activities: design, development, and test and evaluation.
- Typical contributions:
  - provide knowledge of human performance capabilities and limitations, applicable human factors design and evaluation practices, and human factors principles, guidelines, and standards
  - develop and perform human factors analyses and participate in the resolution of identified human factors problems

(7) **Plant Operations**

- Minimum qualifications:
  - has or has held a senior reactor operator license
  - 2 years of experience in relevant nuclear power plant operations
- Typical contributions:
  - provide knowledge of operational activities including task characteristics, HSI characteristics, environmental characteristics, and technical requirements related to operational activities
  - provide knowledge of operational activities in support of HSI activities such as development of HSIs, procedures, and training programs
  - participate in the development of scenarios for HRA evaluations, task analyses, HSI tests and evaluations, validation, and other evaluations

(8) **Computer System Engineering**

- Minimum qualifications:
  - Bachelor's degree in Electrical Engineering or Computer Science, or graduate degree in other engineering discipline (e.g., Mechanical Engineering or Chemical Engineering)
  - 4 years of experience in the design of digital computer systems and real-time systems applications
  - familiarity with the theory and practice of software quality assurance and control
- Typical contributions:
  - provide knowledge of data processing associated with displays and controls

- participate in the design and selection of computer-based equipment such as controls and displays
- participate in the development of scenarios for HRA, validation, and other analyses involving failures of the HSI data processing systems

(9) **Plant Procedure Development**

- Minimum qualifications:
  - Bachelor's degree
  - 4 years of experience in developing nuclear power plant operating procedures
- Typical contributions:
  - provide knowledge of operational tasks and procedure formats, especially as presented in emergency procedure guidelines and operational procedures of current and predecessor plants
  - participate in the development of scenarios for HRA evaluations, task analyses, HSI tests and evaluations, validation, and other evaluations
  - provide input for the development of emergency operating procedures, procedure aids, computer-based procedures, and training systems

(10) **Personnel Training**

- Minimum qualifications:
  - Bachelor's degree
  - 4 years of experience in the development of personnel training programs for power plants
  - experience in the application of systematic training development methods
- Typical contributions:
  - develop content and format of personnel training programs for licensed and non-licensed plant personnel
  - coordinate training issues arising from activities such as HRA, HSI design, and procedure design with the training program
  - participate in the development of scenarios for HRA evaluations, task analyses, HSI tests and evaluations, validation, and other evaluations

(11) **Systems Safety Engineering**

- Minimum qualifications:
  - Bachelor's degree in Science
  - 4 years of experience in system safety engineering
- Typical contributions:
  - identify safety concerns and perform a system safety hazard analysis
  - provide results of system safety hazard analysis to probabilistic risk assessment/HRA and human factors analyses

(12) **Maintainability/Inspectability Engineering**

- Minimum qualifications:
  - Bachelor's degree in Science
  - 4 years of cumulative experience in at least two of the following areas of power plant maintainability and inspectability engineering activity: design, development, integration, and test and evaluation
  - experience in analyzing and resolving plant system and/or equipment-related maintenance problems
- Typical contributions:
  - provide knowledge of maintenance, inspection, and surveillance activities including task characteristics, HSI characteristics, human performance demands, environmental characteristics, and technical requirements related to the conduct of these activities
  - support the design, development, and evaluation of the control room and other HSIs throughout the plant to ensure that they can be inspected and maintained to the specified level of reliability
  - provide input in the areas of maintainability and inspectability to the development of procedures and training
  - participate in the development of scenarios for HSI evaluations including task analyses, HSI design tests and evaluations, and validation

(13) **Reliability/Availability Engineering**

- Minimum qualifications:
  - Bachelor's degree
  - 4 years of cumulative experience in at least two of the following areas of power plant reliability engineering activity: design, development, integration, and test and evaluation
  - knowledge of computer-based, human-interface systems
- Typical contributions:
  - provide knowledge of plant component and system reliability and availability and assessment methodologies to the HSI development activities
  - participate in human reliability analyses
  - participate in the development of scenarios for HSI evaluations, especially validation
  - provide input to the design of HSI equipment to ensure that it meets reliability goals during operation and maintains the specified level of availability

The education and related professional experience of the HFE design team personnel should satisfy the minimum qualification requirements specified above for each of the areas of expertise. Qualifying professional experience (e.g., design, development, analysis) for each area of expertise should be directly

related to those technologies and techniques that will be used in the HFE design and implementation process.

The professional experience is to be satisfied by the HFE design team as a collective whole. Therefore, satisfaction of the professional experience requirements associated with a particular skill area may be realized through the combination of the professional experience of two or more members of the HFE design team who each, individually, satisfy the other defined credentials of the particular skill area but who do not possess all of the specified professional experience. It is recognized that one person may possess multiple skills and that people may have additional responsibilities beyond the HFE design team.

Alternative personal credentials may be accepted as the basis for satisfying the minimum personal qualification requirements specified above. Acceptance of such alternative personal credentials should be evaluated on a case-by-case basis and approved, documented, and retained in auditable plant files by the combined operating license applicant. The following factors are examples of alternative credentials that may be considered acceptable:

- A professional Engineer's license in the skill area may be substituted for the Bachelor's degree.
- Successful completion of all technical portions of an engineering, technology or related science baccalaureate program may be substituted for the Bachelor's degree. The successful completion will be determined by a transcript or other certification by an accredited institution. For example, completion of 80 semester credit hours may be substituted for the baccalaureate requirement. The courses should be in appropriate technical subjects relevant to the skill areas of the HFE design team for which the individual will be responsible.
- Related experience may substitute for education at the rate of 6 semester credit hours for each year of experience up to a maximum of 60 credit hours.
- Where course work is related to job assignments, post-secondary education may be substituted for experience at the rate of 2 years of education for 1 year of experience. Total credit for post-secondary education should not exceed 2 years experience credit.

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P. Lewis, NRC Project Manager

11. ABSTRACT *(200 words or less)*

This document is used by the staff of the Nuclear Regulatory Commission to review the human factors engineering (HFE) programs of applicants for construction permits, operating licenses, standard design certifications, combined operating licenses, and for license amendments. The purpose of these reviews is to help ensure safety by verifying that accepted HFE practices and guidelines are incorporated into the applicant's HFE program. The review methodology provides a basis for performing reviews that address the twelve elements of an HFE program: HFE Program Management, Operating Experience Review; Functional Requirements Analysis and Function Allocation, Task Analysis, Staffing, Human Reliability Analysis, Human-System Interface Design, Procedure Development, Training Program Development, Human Factors Verification and Validation, Design Implementation, and Human Performance Monitoring. Each review element is divided into four sections: Background, Objective, Applicant Submittals, and Review Criteria. References to sources of additional information are also provided for each element.

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