Chapter 18 Human Factors Engineering

18.1 Overview

This chapter presents the Human Factors Engineering (HFE) programs for the ESBWR. As discussed in Subsection 1.1.2.2, this chapter supports the final design approval and standard design certification for the ESBWR Standard Plant. In accordance with a standard design certification under Part 52, this chapter provides technical information, which encompasses the HFE program. The minimum inventory of alarms, displays, and controls presented in this chapter ensures that those human-system interfaces (HSIs) needed to implement the emergency operating procedures (EOPs) and carry out the risk-important human actions identified in the probabilistic risk assessment (PRA) are included in the designs of the Main Control Room (MCR) and Remote Shutdown System (RSS). This minimum inventory of MCR and RSS HSIs supports certification of the ESBWR MCR and RSS design. Because technology is continually advancing, details of the HFE design need not be complete before the Nuclear Regulatory Commission (NRC) issuance of a design certification. The HFE focus is on the design process.

This chapter describes the following:

- ESBWR HSI design goals and bases
- The minimum inventory of MCR and RSS alarms, displays, and controls
- The HSI design features
- The detailed HSI design
- The implementation process for the ESBWR operator interfaces

The incorporation of HFE principles into all phases of the design is described in this chapter. The overall design and implementation process is described in the Licensing Topical Report, titled "Man-Machine Interface System and Human Factors Engineering Implementation Plan" (MMIS and HFE Implementation Plan), Reference 18.1-1, and the HFE implementation plans referenced within the applicable subsections. This presents a comprehensive, iterative design approach for the development of human-centered control and information infrastructure for the ESBWR.

Technical bases for severe accident management (core damage prevention and mitigation strategies and actions to limit radionuclide releases to within offsite dose limits) are documented in item 7 of Tier 1 Table 3.3-2 for HFE. Standard guidelines, procedures, and training modules are developed as described in Reference 18.1-1. The Probabilistic Risk Assessment (PRA) and Human Reliability Analysis (HRA) confirm that Emergency Procedure Guidelines (EPGs) and severe accident guidance effectively address:

- Preventing core damage
- Recovering from core damage
- Maintaining containment integrity

- Minimizing radionuclide releases

The standard guidance and EPGs are used to develop and validate site-specific severe accident mitigation guidelines and procedures that satisfy Reference 18.1-2.

HFE Program Goals – The general objectives of the program are stated in human-centered terms, which, as the HFE program develops, are refined and used as a basis for HFE planning, testing and evaluation activities. HFE design goals ensure:

- Personnel tasks are accomplished within time and performance criteria.
- HSIs, procedures, staffing/qualifications, training, management, and organizational variables support a high degree of operating crew situational awareness.
- Allocation of functions accommodates human capabilities and limitations.
- Operator vigilance is maintained.
- Acceptable operator workload is met.
- Operator interfaces contribute to an error-free environment.
- Error detection and recovery capabilities are provided.

Assumptions and Constraints – An assumption or constraint is an aspect of the design identified, such as specific staffing plans or the use of specific HSI technology, that is an input to the HFE program rather than the result of HFE analyses or evaluations.

The assumptions and constraints on the design include the following:

1. Predecessor Advanced Boiling Water Reactor (ABWR) designs – The use of proven Man-Machine Interface System (MMIS) design from predecessor ABWR plants is addressed in Subsection 18.1.1.
2. Standard Design Features – The ESBWR control room HSI design contains a group of standard features described in Subsection 18.1.3.
3. Safety requirements – Design inputs from regulations and regulatory guidance are discussed in Subsection 18.1.1.
4. Staffing plan – The initial staffing plan is addressed in Section 18.6.

Applicable Facilities – The HFE program addresses the Main Control Room (MCR), Remote Shutdown System (RSS), Technical Support Center (TSC), Emergency Operations Facility (EOF) displays, and Local Control Stations (LCSs) with safety-related functions or as defined by task analysis.

Applicable HSIs, Procedures, and Training – The applicable HSIs, procedures, and training included in the HFE program include operations, accident management, maintenance, test, inspection and surveillance interfaces (including procedures) for systems that have safety

significance. This includes monitoring the designs being presented by ESBWR suppliers, to ensure that supplier designs are consistent with the HFE requirements of the ESBWR HFE Program.

A minimum inventory of HSIs (alarms, displays, and controls) needed to implement the plant's emergency operating procedures, bring the plant to a safe condition, and to carry out those human actions shown to be important from the probabilistic risk assessment is established and verified in the HFE program. The minimum inventory of HSIs for the MCR and RSS is documented in Tables 18.1-1a and 18.1-1b.

Applicable Plant Personnel – Plant personnel, both licensed and unlicensed, addressed by the HFE program are delineated in Section 18.6. The staff members include those that perform tasks that are directly related to plant safety.

The MMIS employs digital technology to implement the majority of the monitoring, control, and protection functions for the ESBWR. Standardization of hardware and software, and modularity of design is used to simplify maintenance and provide protection against obsolescence.

The HSI design implementation activities include the development of dynamic models for evaluating the overall plant response as well as individual control systems, including operator actions. These dynamic models are used to:

1. Analyze both steady state and transient behaviors
2. Confirm the design of the advanced alarm system concepts
3. Confirm the adequacy of control schemes
4. Confirm the allocation of control to a system or an operator
5. Develop and validate plant operating procedures
6. Incorporate use of simulators

Using part-task simulation, an initial set of systems is identified through modeling, including the development of the graphical user interfaces. The part-task simulator is used in preliminary ESBWR design and expanded to include ESBWR-unique design features. The types of simulators are further addressed in Section 18.10.

As the ESBWR design progresses, the part-task simulator proceeds through a series of iterative evaluations resulting in the development of a complete control room full-scope simulator. Simulators are the focal point for operator evaluations and feedback checkpoints throughout the MMIS design process. The general development of twelve key implementation plans, analyses, and evaluation are identified in Reference 18.1-1. These are:

- Operating Experience Review (OER)
- Functional Requirements Analysis (FRA)
- Allocation of Functions (AOF)

- Task Analysis (TA)
- Staffing and Qualifications (S&Q)
- Human Reliability Analysis (HRA)
- Human-System Interface (HSI)
- Procedure Development
- Training Development
- Human Factors Verification and Validation (V&V)
- Design Implementation
- Human Performance Monitoring (HPM)

The ESBWR Defense-In-Depth and Diversity (D3) analysis is design input to the system FRA during each of the iterations. The following important aspects of defense-in-depth are identified in RG 1.174.

- Balance is preserved among prevention of core damage, prevention of containment failure, and consequence mitigation.
- Reliance on programmatic activities to compensate for possible weaknesses in plant design is minimized. 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.
- Defenses against potential common cause failures are preserved, and the potential for the introduction of new common cause failure mechanisms is assessed. Caution is exercised in crediting new HAs to ensure that the possibility of significant common cause errors is avoided.
- Independence of barriers is preserved.
- Human error defenses are preserved. For example, procedures are established 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 Title 10, Code of Federal Regulations, Part 50 (10 CFR 50) is maintained.

Safety margins are used in deterministic analyses to account for uncertainty and provide an added margin to provide adequate assurance that the various safety limits or criteria are not violated. A safety margin can be added if desired to HAs by demonstrating the action can be performed within some time interval (or margin) that is less than the time identified by the analysis.

Design goals and design bases for the HSI in the MCR and in other applicable facilities are established in this chapter.

18.1.1 Design Goals and Design Bases

The primary goal of HSI designs is to facilitate safe, efficient, and reliable operator performance during all phases of normal plant operation, abnormal events, and accident conditions. To achieve this goal, information displays, controls, and other interface devices in the control room and other plant areas are designed and implemented in a manner consistent with good human factors engineering practices. Further, the following specific design bases are adopted:

- HSI design promotes efficient and reliable operation through application of automated operational capabilities.
- HSI design uses only proven technology as defined in Reference 18.1-1.
- The most recent predecessors for the project are the ABWR plants:
    - Lungmen project (Taiwan Power)
    - Kashiwazaki-Kariwa 6 & 7 (Tokyo Electric Power Company)
    - Hamaoka 5 (Chubu Electric)
    - Shika 2 (Hokuriku Electric Power)
- Safety-related systems monitoring and control capability is provided in full compliance with regulations regarding divisional separation and independence.
- HSI design is highly reliable and provides functional redundancy such that sufficient displays and controls are available in the MCR and remote locations to conduct an orderly reactor shutdown and to cool the reactor down to safe shutdown conditions, even during design basis equipment failures.
- The principal functions of the Safety Parameter Display System as required by Supplement 1 to NUREG-0737 are integrated into the HSI design.
- Accepted human factors engineering principles are used for the HSI design in meeting the requirements of GDC 19.
- ESBWR Style Guide is based on NUREG-0700.
- The design basis for the RSS as specified in Section 7.4.

Detailed design criteria are specified as part of Section 18.2 and within the references of the applicable subsections. These design criteria are used to govern and direct all ESBWR HSI design implementations. These detailed design criteria encompass the set of necessary and sufficient design implementation-related activities. These design implementation-related activities are required to maintain the implemented HSI design in compliance with accepted HFE principles and digital electronics equipment and software development methods.

Also, as part of the detailed design implementation process, operator task analysis is performed as a basis for evaluating details of the design and specifying HSI requirements. The evaluation of the

integrated control room design includes the confirmation of the ESBWR MCR standard design features.

18.1.2 Planning, Development, and Design

An integrated program plan described in licensing topical reports is implemented to incorporate HFE principles and to achieve an integrated design of the instrumentation and control (I&C) systems and HSI of the ESBWR. Reference 18.1-1, the MMIS and HFE Implementation Plan, and the HFE implementation plans referenced within the applicable subsections present a comprehensive, synergistic design approach with provisions for task analyses and human factors evaluations. Also included are formal decision analysis procedures to facilitate selection of design features, which satisfy top-level requirements and goals of individual systems and the overall plant.

The program plan and the associated procedures provide guidance for the conduct of the ESBWR HSI design development activities, including definition of the standard design features of the control room HSI.

18.1.2.1 Standard Design Features

The ESBWR HSI concept design includes a group of standard features, which form the foundation for the detailed HSI design. The development of the control room HSI standard design features is accomplished through:

- Incorporation of all ESBWR minimum inventory HSIs contained in Tables 18.1-1a and 18.1-1b
- Consideration of existing control room operating experience
- Review of trends in control room designs and existing control room data presentation methods
- Evaluation of new HSI technologies, alarm reduction, and presentation methods
- Validation testing of a dynamic control room prototype

The prototype is evaluated under simulated normal and abnormal reactor operating conditions by experienced nuclear plant control room operators. Following the completion of the prototype tests and result analysis, the standard control room HSI design features are finalized.

18.1.2.2 Inventory of Controls and Instrumentation

The results from the HFE operations analysis (FRA, AOF, and TA) and the important operator actions identified in the PRA provide the bases for an analysis of the information and control capability needs of the MCR operators.

The results from the HFE analysis of the actions performed in the MCR to implement the EOPs and carry out the risk-important human actions identified in the PRA provide the basis for the information and control capability needs of the operators. This analysis resulted in the ESBWR

MCR minimum inventory HSI listing presented in Table 18.1-1a. The process used to develop the ESBWR MCR minimum inventory is described in Section 18.5.

18.1.2.3 Detailed Design Implementation Process

The process for detailed equipment design implementation of the ESBWR HSI is described in Reference 18.1-1. This process builds upon the standard HSI design features discussed herein. Embedded in the process are a number of conformance reviews in which various aspects and outputs of the process are evaluated against established design acceptance criteria.

18.1.3 Control Room Standard Design Features

The control room standard design features are based upon proven technologies and have been demonstrated, through broad scope control room dynamic simulation tests and evaluation, to satisfy the ESBWR HSI design goals and design bases. Validation of the implemented MCR design includes evaluation of the standard design features performed as part of the design implementation process described in Reference 18.1-1.

18.1.4 Remote Shutdown System

The RSS provides a means to safely shut down the plant from outside the main control room. It provides control of the plant systems needed to bring the plant to hot shutdown, with the subsequent capability to attain safe shutdown, in the event that the control room becomes uninhabitable.

The results from the HFE analysis of the actions performed at the RSS to attain and maintain safe, stable shutdown provides the basis for the information and control capability needs of the operators. This analysis resulted in the ESBWR RSS minimum inventory HSI listing presented in Table 18.1-1b. The process used to develop the ESBWR RSS minimum inventory is described in Section 18.5.

The RSS design is described in Section 7.4. Parameters displayed and controlled from Division I and Division II in the MCR are also displayed and controlled from the RSS Panels.

18.1.5 Systems Integration

18.1.5.1 Safety-Related Systems

The operator interfaces with the safety-related systems through a variety of methods. Dedicated controls are used for system initiation and logic reset, while system mode changes are made with other controls. Safety-related Video Display Units (VDUs) provide capability for individual safety equipment control, status display, and monitoring. Nonsafety-related VDUs are used for additional safety-related system monitoring. The large fixed-position display provides plant overview information. Instrumentation and control aspects of the microprocessor-based Safety System Logic and Control (SSLC) are described in Chapter 7.

Divisional separation for control, alarm, and display equipment is maintained. The SSLC processors provide alarm signals to the respective safety-related alarm processors and provide display information to the divisionally dedicated VDUs. The SSLC microprocessors communicate with the respective divisional VDU controllers through the Safety-Related Distributed Control and Information System (Q-DCIS).

The divisional VDUs have on-screen control capability and are classified as safety-related equipment. These VDUs provide control and display capabilities for individual safety-related systems.

Divisional isolation devices are provided between the safety-related systems and nonsafety-related communication networks so that failures in the nonsafety-related equipment do not affect the ability of safety-related systems to perform their design functions. The nonsafety-related communication network is part of Nonsafety-Related Distributed Control and Information System (N-DCIS) described in Chapter 7.

Safety-related system process parameters, alarms, and system status information from the SSLC are communicated to the N-DCIS through isolation devices for use by other equipment connected to the communication network. Spatially and functionally dedicated controls, which are safety-related, qualified and divisionally separated, are available in the control room for selected operator control functions. These controls communicate with the safety-related system logic units.

18.1.5.2 Nonsafety-Related Systems

Operational control of nonsafety-related systems is accomplished through the use of nonsafety-related, on-screen control VDUs. Nonsafety-related data is processed through the N-DCIS, which provides redundant and distributed instrumentation and control data communications networks. Thus, monitoring and control of interfacing plant systems are supported.

Alarms for entry conditions into the emergency operating procedures are provided by the alarm processing units, both safety-related and nonsafety-related. Equipment level alarm information is presented by the computer system through the N-DCIS on the main control console VDUs.

The fixed position wide display panel provides the critical plant operating information such as power, water level, temperature, pressure, flow, and status of major equipment. In addition, a mimic display will indicate the availability of safety-related systems.

18.1.6 Detailed Design of the Operator Interface System

The standard design features of the ESBWR main control room HSI, discussed in Subsection 18.1.3, provide the framework for the detailed equipment hardware and software designs developed following the design and implementation process described in Section 18.2. This process is illustrated in Figure 18.1-1.

Design criteria for the HFE activities are highlighted within Sections 18.2 through 18.13, and provided in detail in Reference 18.1-1 and the HFE implementation plans referenced within the applicable subsections. These criteria are used to govern and direct all ESBWR HSI design implementations that reference the certified design. These detailed design criteria encompass the set of necessary and sufficient design implementation-related activities. These criteria are required to maintain the implemented HSI design in compliance with accepted HFE principles as well as accepted digital electronics equipment and software development methods.

Also, as part of the detailed design implementation process described in Section 18.2 and Reference 18.1-1, operator task analysis is performed as a basis for evaluating details of the design implementation and HSI requirements. The evaluation of the integrated control room design includes the confirmation of the ESBWR MCR standard design features.

18.1.7 COL Information

None.

18.1.8 References

18.1-1 *GE Hitachi Nuclear Energy, "ESBWR Man-Machine Interface System and Human Factors Engineering Implementation Plan," NEDE-33217P, Class III (Proprietary), Revision 6, February 2010, and NEDO-33217, Class I (Non-proprietary), Revision 6, February 2010.*

18.1-2 Nuclear Energy Institute, "Severe Accident Issue Closure Guidelines," NEI 91-04, Revision 1, December 1994.

Table 18.1-1a Minimum Inventory of MCR Alarms, Displays, and Controls (Sheet 1 of 2)

Description	Alarm	Display	Control
Reactor Power	X	X	
Reactor Pressure	X	X	
Reactor Water Level	X	X	
Containment Water Level		X	
Suppression Pool Level	X	X	
Average Drywell Temperature	X	X	
Suppression Pool Bulk Average Temperature	X	X	
Drywell Pressure	X	X	
Wetwell Pressure		X	
Containment Isolation Valves		X	X
Containment Radiation		X	
Drywell Hydrogen Concentration	X	X	
Wetwell Hydrogen Concentration	X	X	
Drywell Oxygen Concentration	X	X	
Wetwell Oxygen Concentration	X	X	
Isolation Condenser Valves		X	X
Isolation Condenser Pool Level	X	X	
Shutdown Cooling Initiation			X
Passive Containment Cooling Pool Level	X	X	
Gravity-Driven Cooling Pool Level		X	
Gravity-Driven Cooling Injection Valves		X	X
Gravity-Driven Cooling Equalization Valves		X	X
Reactor Scram	X	X	X
Main Steam Isolation	X	X	X
Main Steam Relief Valves		X	X
Standby Liquid Control Accumulator Level		X	
Standby Liquid Control Initiation			X
Standby Liquid Control Accumulator Isolation Valves	X	X	X
Automatic Depressurization System Inhibit	X		X
Depressurization Valves (DPV)		X	X
Containment High Pressure Nitrogen System Status	X		

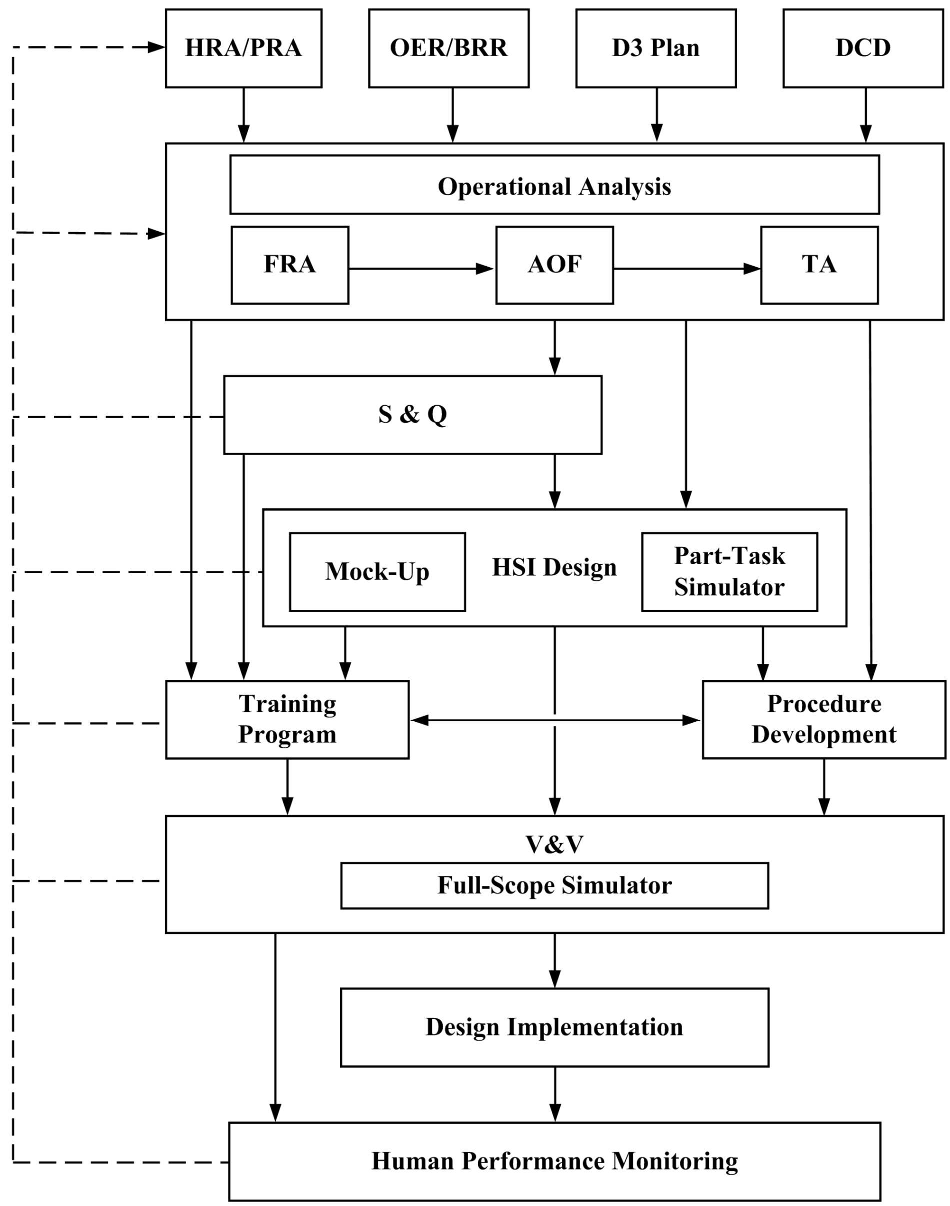
Table 18.1-1a Minimum Inventory of MCR Alarms, Displays, and Controls (Sheet 2 of 2)

Description	Alarm	Display	Control
Reactor Building Area Temperature High	X		
Reactor Building Ventilation Exhaust Radiation High	X	X	
Reactor Building Area Radiation High	X		
Reactor Building Area Water Level High	X		
Reactor Building Ventilation Isolation		X	X

Table 18.1-1b Minimum Inventory of RSS Alarms, Displays, and Controls

Description	Alarm	Display	Control
Reactor Pressure	X	X	
Reactor Water Level	X	X	
Isolation Condenser System	X	X	X
Isolation Condenser Pool level	X	X	
Main Steam Isolation	X	X	X

Figure 18.1-1 HFE Implementation Process



18.2 MMIS and HFE Program Management

18.2.1 HFE Program and MMIS and HFE Implementation Plan

The HFE design team establishes the HFE Program and the MMIS and HFE Implementation Plan described in Reference 18.2-1. The plan provides overall direction and integration of the HFE-related design implementation and evaluation activities for the specific HSI scope. The scope includes the MCR, RSS, TSC, EOF, and LCSs (those with a safety-related function or as identified by task analysis) areas of operational interface.

The MMIS and HFE Implementation Plan supplements Subsection 18.2.3 to identify the qualifications and experience of individuals comprising the HFE design team, and establishes the processes the HFE design team performs in its functions. Included in the MMIS and HFE Implementation Plan is a system for documenting human factors issues identified throughout the design process, and the actions taken to resolve those issues. The HFE design team also establishes the implementation plans for conducting each of the following HFE-related activities:

- Operating Experience Review
- Functional Requirements Analysis
- Allocation of Functions
- Task Analysis
- Staffing and Qualifications
- Human Reliability Analysis
- Human-System Interface Design
- Procedure Development
- Training Development
- Human Factors Verification and Validation
- Design Implementation
- Human Performance Monitoring

The implementation plans establish methods and criteria consistent with accepted HFE practices and principles for the conduct of each of the HFE-related activities.

18.2.2 MMIS and HFE Implementation Plan

1. The MMIS and HFE Implementation Plan establishes:
    a. Methods and criteria for the development and evaluation of the MCR, RSS, TSC, EOF and LCSs HSIs, which are consistent with accepted HFE practices and principles.
    b. The methods for addressing:

i. Ability of the operating personnel to accomplish assigned tasks

ii. Operator workload levels and vigilance

iii. Operating personnel situational awareness

iv. Operator information processing requirements

v. Operator memory requirements

vi. Potential for operator error

c. HSI design and evaluation scope that applies to the MCR, RSS, TSC, EOF, and applicable LCSs.

The scope addresses normal, abnormal and emergency plant operations as well as test and maintenance interfaces that impact the function of the operations personnel. The HSI scope also addresses the development of operating technical procedures for normal, abnormal, and emergency plant operations and the identification of personnel training needs applicable to the HSI design.

d. The HFE design team responsibilities for:

i. Development of HFE plans and procedures.

ii. Oversight and review of HFE design, development, test, and evaluation activities.

iii. Initiation, recommendation, and provision of solutions for problems identified in the implementation of the HFE activities.

iv. Verification of resolution effectiveness.

v. Assurance that HFE activities comply with HFE plans and procedures.

vi. Phasing of activities.

vii. Methods for identification, closure, and documentation of human factors issues.

viii. HSI design configuration control procedures.

2. The MMIS and HFE Implementation Plan also establishes the following items:

a. Human factors issues identified throughout the development and evaluations of the MCR, RSS, TSC, EOF and LCSs HSI design implementation are addressed.

b. HFE issues/concerns are tracked when first identified. Each action taken to eliminate or reduce the issue/concern is documented.

c. Final resolution of the issue/concern, as accepted by the HFE design team, is documented along with information regarding HFE design team acceptance.

d. LCSs HSI design implementation.

e. MCR, RSS, TSC, EOF and applicable LCSs designs are implemented using HSI technologies that are consistent with those defined in Subsection 18.1.3.

f. Alternative HSI concepts and new HSI equipment technologies are considered for application in the MCR, RSS, TSC, EOF and LCSs design implementations. For new technology uses, the following is accomplished:

   i. A review of the industry experience with the operation of selected new HSI technologies is conducted.

   ii. The OER of those new HSI equipment technologies includes both a review of literature and interviews with personnel experienced with the operation of those systems.

   iii. Pertinent human factors issues relevant to similar system applications of new HSI technologies are documented.

   iv. Any relevant HFE issues/concerns associated with those selected new HSI equipment technologies, identified through the conduct of the OER, are tracked for closure.

3. Reviews of HSI operating experience are conducted in accordance with Section 18.3.

4. The MMIS and HFE Implementation Plan document includes:

   a. Purpose and organization of the plan.

   b. Relationship between the HFE program and the overall plant equipment procurement and construction program (organization and phasing).

   c. Definition of the HFE design team and their activities. These include:

      i. Description of the HFE design team function within the broader scope of the plant equipment procurement and construction program, including charts to show organizational and functional relationships, reporting relationships, and lines of communication.

      ii. Description of the responsibility, authority and accountability of the HFE design team organization.

      iii. Description of the process through which the design team resolves HFE issues.

      iv. Description of the process through which the HFE design team makes technical decisions.

      v. Description of the tools and techniques (for example, review forms and documentation) utilized by the HFE design team in fulfilling their responsibilities.

      vi. Description of the HFE design team staffing, job descriptions of the individual HFE design team personnel and their qualifications.

      vii. Definitions of the procedures governing the internal management of the HFE design team.

d. Definition of the Human Factors Engineering Issue Tracking System (HFEITS) and its implementation, including:

   i. Individual HFE design team member responsibilities regarding HFE issue identification, logging, issue resolution, and issue closeout.

   ii. Procedures and documentation requirements regarding HFE issue identifications; including:

      - Description of the HFE issue.
      - Effects of the issue.
      - Assessment of the criticality.
      - Determination of possible negative consequences (for example, unacceptable HSI performance).

   iii. Procedures and documentation requirements regarding HFE issue resolution; including:

      - Development, evaluation and documentation of proposed solutions.
      - Implemented solutions.
      - Evaluated residual effects.
      - Evaluated criticality and likelihood of the implemented resolution of the HFE issue manifesting itself into unacceptable HSI performance.

e. Identification and description of the HFE implementation plans.

f. Definition of the phasing of HFE program activities; including:

   i. The plan for completion of HFE tasks which addresses the relationships between HFE elements and activities, the development of HFE reports, and the conduct of HFE reviews.

   ii. Identification of other plant equipment procurement and construction activities that are related to HFE Design team activities but outside the scope of the team (for example, I&C equipment manufacture).

   iii. Definition of HFE documentation requirements and procedures for retention and retrieval.

   iv. Description of the HFE Program requirements communicated to applicable personnel and organizations. Personnel and organizations include those whom are subcontracted and are responsible for the performance of work associated with the MCR, RSS, TSC, EOF, and LCSs design implementation (See Figure 18.1-1).

18.2.3 Human Factors Engineering Design Team Composition

The composition of the HFE design team includes, as a minimum, the technical skills presented below:

1. The education and related professional experience of the HFE design team personnel satisfies the minimum personal qualification requirements specified in number (3), below, for each of the areas of required skills. In those skill areas where related professional experience is specified, qualifying experience of the individual HFE design team personnel includes experience with previous plants in the MCR, RSS, TSC, EOF and LCS HSI designs and design implementation activities. The required professional experiences presented in the listed personal qualifications are satisfied by the HFE design team as a collective whole. The requisite professional credentials and experience are met collectively even if a given individual does not meet all qualifications. Similarly, an individual member of the HFE design team may possess all of the credentials sufficient to satisfy the HFE design team qualification requirements for two or more of the defined skill areas.
2. Alternative personal credentials may be accepted as the basis for satisfying the minimum personal qualification requirements specified below. Acceptance of such alternative personal credentials are evaluated on a case-by-case basis and approved, documented, and retained in auditable plant construction files. The following factors are examples of alternative credentials, which are considered acceptable:
    a. Professional Engineer’s license in the required skill area may be substituted for the required Bachelor’s degree.
    b. Related experience may substitute for education at the rate of six semester credit hours for each year of experience up to a maximum of 60 hours credit.
    c. Where course work is related to job assignments, post-secondary education may be substituted for experience at the rate of two years of education for one year of experience. Total credit for post-secondary education will not exceed two years experience credit.
3. Required Skill Area /Personal Qualification:
    a. Technical Project Management

       Bachelor’s degree, and five years experience in nuclear power plant design or operations, and three years management experience.
    b. Systems Engineering

       Bachelor of Science degree, and four years cumulative experience in at least three of the following areas of systems engineering: design, development, integration, operation, and test and evaluation.
    c. Nuclear Engineering

Bachelor of Science degree, and four years nuclear design, development, test or operations experience.

d. Instrumentation and Control (I&C) Engineering

Bachelor of Science degree, and four years experience in design of hardware and software aspects of process control systems, and experience in at least one of the following areas of I&C: engineering development, power plant operations, and test and evaluation, and familiarity with the theory and practice of software quality assurance and control.

e. Architect Engineering

Bachelor of Science degree, and four years power plant control room design experience.

f. Human Factors Engineering

Bachelor’s degree in Human Factors Engineering, Engineering Psychology, or related science, and four years cumulative experience related to the human factors aspects of human-computer interfaces. Qualifying experience includes at least the following activities within the context of large-scale human-machine systems (for example, process control): design, development, and test and evaluation, and four years cumulative experience related to the human factors field of ergonomics. Qualifying experience will include experience in at least two of the following areas of human factors activities: design, development, and test and evaluation.

g. Plant Operations

Have or have held a Senior Reactor Operator (SRO) license; two years experience in Boiling Water Reactor (BWR) nuclear power plant operations.

h. Computer System Engineering

Bachelor’s degree in Electrical Engineering or Computer Science, or graduate degree in other engineering discipline (for example, Mechanical Engineering or Chemical Engineering), and four years experience in the design of digital computer systems and real time systems applications.

i. Plant Procedure Development

Bachelor’s degree, and four years experience in developing nuclear power plant operating procedures.

j. Personnel Training

Bachelor’s degree, and four years experience in the development of personnel training programs for power plants, and experience in the application of systematic training development methods.

k. System Safety Engineering

Bachelor's degree, and four years of experience in system safety engineering.

l. Maintainability/Inspectability Engineering

Bachelor's degree, and four years 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.

m. Reliability/Availability Engineering

Bachelor's degree, and four years cumulative experience in at least two of the following areas of power plant reliability engineering activity: design, development, integration, and test and evaluation, and knowledge of computer-based human interface systems.

18.2.4 COL Information

None.

18.2.5 References

18.2-1 *GE Hitachi Nuclear Energy, "ESBWR Man-Machine Interface System and Human Factors Engineering Implementation Plan," NEDE-33217P, Class III (Proprietary), Revision 6, February 2010, and NEDO-33217, Class I (Non-proprietary), Revision 6, February 2010.*

18.3 Operating Experience Review

The OER process is conducted in accordance with References 18.3-1 and 18.3-2 and supports HFE by identifying HFE-related safety issues. An overview of the OER topics is summarized in the subsections below.

18.3.1 Objectives and Scope of Operating Experience Review

The objectives of the OER process are to obtain information and lessons learned from operating experience to support design of ESBWR systems. The scope of the analyses is to obtain, evaluate, and incorporate lessons learned from the experience into the ESBWR design. OERs related to the following areas are considered in the development of the plant system, and operational aspects of the ESBWR design:

- Predecessor plant(s) and systems
- Experience in industries with applicable systems
- Industry HSI experience
- Risk-important Human Actions (HAs)
- Specifically-identified industry issues
- Issues identified by plant personnel

18.3.2 Operating Experience Review Methodology

The OER process methodology establishes the process and procedures for evaluating operating, design, and construction experience, thus ensuring that the applicable important industry experiences are provided in a timely manner to those designing and constructing the plant, as required by 10 CFR 50.34 (f)(3)(i).

- The methods for identifying the operating experience includes:
  - Operating experience for the selected HFE technology components from relevant predecessor plants and systems.
  - Risk-important human actions, recognized industry issues.
  - Issues identified by plant personnel.
- The methods for analysis and evaluation of operating experience include:
  - Use of summarized issues from industry sources
  - Development of insights from event reviews
  - Development of design solutions to reduce human error
- The method for keeping track of the process includes the use of the HFEITS, which permits tracking and review of the issues identified and addressed in the design.

18.3.2.1 **Predecessor Plants and Systems**

Experience from the entire BWR fleet of reactors is considered in the ESBWR design. The operating experience information is made available to design engineers to support development of design features that are expected to reduce human error. Likewise, positive features of previous designs are identified, evaluated, and retained. A collection of baseline design inputs from the system designs of predecessor plants is established in an ESBWR design baseline review record (BRR). The BRR includes industry experience related to the plant and systems of the ESBWR.

18.3.2.2 **Risk-Important Human Actions**

The OER process addresses the risk-important HAs from predecessor plants and other BWRs, including:

- Identification of risk-important HAs in the predecessor plant PRAs and HRAs.
- Determination if they are still risk-important to the ESBWR design via the design level ESBWR PRA output.
- Application of HAs to identify scenarios where these actions are called for in predecessor operations.
- Noting aspects of the predecessor design that assured success for HAs.
- Identifying insights related to needed improvements in human performance if errors have occurred in task execution.

The OER process identifies and documents operational experience related to risk-important HAs in the ESBWR plant determined to be different from those of the predecessor plant.

18.3.2.3 **Human Factors Engineering Technology**

The OER associated with proposed HFE technology in the ESBWR design is described in the OER documentation and summarized in the OER Results Summary Report (RSR). For example, if a computer operated support system, computerized procedures, or advanced automation are planned, HFE issues associated with such use are described.

18.3.2.4 **Recognized Industry Issues**

The process for recognizing how industry HFE issues are addressed in the ESBWR design includes consideration of items applicable to the categories identified in NUREG/CR-6400. The categories are:

- Unresolved safety issues/generic safety issues
- Three Mile Island 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 experience reviews

18.3.2.5 Issues Identified by Plant Personnel

The OER plan includes the use of plant personnel interviews to supplement operating experience related to plant operations and HFE design in predecessor plants and systems. Personnel interviews include the following:

- Plant Operations:
  - Normal plant evolutions (for example, startup, full power, and shutdown).
  - Instrument failures (for example, 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), and break in MUX line).
  - HSI equipment and processing failure (for example, loss of video display units, loss of data processing, and loss of large overview display).
  - Transients (for example, turbine trip, loss of offsite power, station blackout, loss of all feedwater, loss of service water, loss of power to selected buses or control room power supplies, and safety/relief valve transients).
  - Accidents (for example, main steam line break, positive reactivity addition, control rod insertion at power, anticipated transient without scram (ATWS), and various-sized loss-of-coolant accidents).
  - Reactor shutdown and cool-down 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

18.3.2.6 Issue Analysis, Tracking, and Review

Subsection 18.2.2 (4) d describes how OER issues are tracked.

18.3.3 Results of Operating Experience Review

The results of the OER activity are summarized in a RSR. The content of the OER RSR is described in Reference 18.3-2.

18.3.4 COL Information

None.

18.3.5 References

18.3-1 *GE Hitachi Nuclear Energy, "ESBWR Man-Machine Interface System and Human Factors Engineering Implementation Plan," NEDE-33217P, Class III (Proprietary), Revision 6, February 2010, and NEDO-33217, Class I (Non-proprietary), Revision 6, February 2010.*

18.3-2 *GE Hitachi Nuclear Energy, "ESBWR Human Factors Engineering Operating Experience Review Implementation Plan," NEDO-33262, Class I (Non-proprietary), Revision 3, January 2010.*

18.4 Functional Requirements Analysis and Allocation of Functions

The FRA and AOF are conducted in accordance with the HFE program guidance described in Reference 18.4-1.

18.4.1 Functional Requirements Analysis Implementation Plan

The FRA process is conducted in accordance with the FRA Implementation Plan, Reference 18.4-2. The implementation plan establishes a functional requirements process that conforms to ESBWR plans and applicable regulatory requirements. The plant-level and system-level goals and functions are systematically analyzed concurrently. The functional relationships between plant functions and system functions are then reconciled through system function gap analysis. The output of this gap analysis is used to ensure that plant-level and system-level goals are both met.

18.4.1.1 Scope of Functional Requirements Analysis

The FRA Implementation Plan establishes the following scope elements.

1. Objectives, performance requirements, and constraints.
2. Methods and criteria for conducting the Plant-level Functional Requirements Analysis in accordance with accepted human factors principles and practices.
3. Methods and criteria for conducting the System Functional Requirements Analysis in accordance with accepted human factors principles and practices.
4. System requirements that define the system functions.
5. Resultant system configuration changes which lead to HSI requirements.
6. Critical Safety Functions resulting from probabilistic and deterministic evaluations.
7. Descriptions for each identified function.
8. Overall system configuration design.

18.4.1.2 Methods of Functional Requirements Analysis

The FRA Implementation Plan establishes methods to:

1. Conduct the FRA consistent with accepted HFE methods.
2. Denote the ESBWR mission, goals, and operating states.
3. Identify Critical Safety Functions.
4. Validate system functions identified in the ESBWR System Design Specifications (SDSs) from an HFE perspective.
5. Define the relationships between high-level functions and plant systems.
6. Reconcile any differences between Plant-level analyses and the SDS.

7. Develop a functional structure that can be used to assess the impact of design, staffing, training, procedure, and HSI changes on the ability of operators to monitor and coordinate activities.

18.4.1.3 **Results of Functional Requirements Analysis**

The results of the FRA activity are summarized in a RSR. The content of the FRA RSR is described in Reference 18.4-2. The FRA RSR may be combined with the RSR(s) from AOF and TA.

18.4.2 **Allocation of Functions Implementation Plan**

The AOF process is conducted in accordance with the AOF Implementation Plan, Reference 18.4-3. The implementation plan establishes an allocation of function process that conforms to ESBWR plans and applicable regulatory requirements. Every system-level and plant-level function from the FRA that requires monitoring or control is analyzed and allocated to human, machine, or shared ownership by the AOF process. AOF places emphasis on HAs that have been found to affect plant risk by means of HRA/PRA. The probability of successful completion of these tasks is increased by proper allocation of supporting functions such as machine backup, machine limits on human actions, and supporting automations.

18.4.2.1 **Scope of Allocation of Functions**

The AOF Implementation Plan establishes the following scope elements.

1. Objectives, performance requirements, and constraints are defined.
2. Methods and criteria for conducting the AOF are in accordance with accepted human factors principles and practices.
3. System and function requirements define function allocation restraints.
4. The results of the HRA/PRA, OER/BRR, and deterministic evaluations are included inputs.
5. Each function identified in the FRA that requires monitoring or control is allocated.
6. AOF outputs are sets of logical, coherent, and meaningful tasks.
7. AOF scope includes the full range of plant conditions.

18.4.2.2 **Methods of Allocation of Functions**

The AOF Implementation Plan establishes methods to:

1. Conduct the AOF consistent with accepted HFE methods.
2. Promote the ESBWR mission, goals, and philosophy.
3. Allocate functions between human, machine and shared control.
4. Coordinate human and machine tasks for shared functions during normal, abnormal, and emergency operation.

5. Coordinate human and machine tasks for shared surveillance functions.
6. Coordinate human and machine tasks for shared maintenance functions.
7. Provide analysis method to assess the impact of design, staffing, training, procedure, and HSI changes on the ability of operators to monitor and coordinate activities.

18.4.2.3 Results of Allocation of Functions

The results of the AOF activity are summarized in a RSR. The content of the AOF RSR is described in Reference 18.4-3. AOF RSR may be combined with the FRA or TA RSRs.

18.4.3 COL Information

None.

18.4.4 References

18.4-1 *GE Hitachi Nuclear Energy, "ESBWR Man-Machine Interface System and Human Factors Engineering Implementation Plan," NEDE-33217P, Class III (Proprietary), Revision 6, February 2010, and NEDO-33217, Class I (Non-proprietary), Revision 6, February 2010.*

18.4-2 *GE Hitachi Nuclear Energy, "ESBWR Human Factors Engineering Functional Requirements Analysis Implementation Plan," NEDO-33219, Class I (Non-proprietary), Revision 4, February 2010.*

18.4-3 *GE Hitachi Nuclear Energy, "ESBWR Human Factors Engineering Allocation of Function Implementation Plan," NEDE-33220P, Class III (Proprietary), Revision 4, February 2010, and NEDO-33220, Class I (Non-proprietary), Revision 4, February 2010.*

18.5 Task Analysis

Task analysis is performed in two segments:

- MCR and RSS minimum inventory HSI determination (complete)
- Detailed Design (including the design, detailed, and economic phases of task analysis)

MCR and RSS minimum inventory HSI determination task analysis was performed as described in Subsection 18.5.1.

The task analysis process for detailed HSI design is conducted in accordance with References 18.5-1 and 18.5-2.

18.5.1 MCR and RSS Minimum Inventory HSI Determination

The following paragraphs describe the detailed and comprehensive process by which the functions and tasks necessary for the operators to implement the emergency operating procedures, and to carry out those human actions shown to be important from the PRA was broken down into elements (discrete task, action, or function). Also presented is the process by which these elements were analyzed through task analysis to determine what HSIs (alarms, displays, and controls) must be present to provide for their successful completion.

18.5.1.1 Assumptions

ESBWR minimum inventory development process assumptions include:

- Minimum inventory HSI is defined as the fixed alarms, displays, and controls necessary for the operators to implement the emergency operating procedures, and to carry out those human actions shown to be important from the PRA.
- The minimum inventory development team, with the support of other engineering staff, performs the analysis and documentation activities described in this plan, and manages the activity through verification. The minimum inventory development team is comprised of personnel with experience in at least the following areas:
  - Plant operations.
  - Plant procedure development and implementation.
  - Emergency operating procedure/severe accident guideline (EOP/SAG) development and implementation.
- The ESBWR design basis provides the events used to determine the applicability of EOP steps for the minimum inventory of alarms, displays, and controls.
- The ESBWR is designed to operate with a high degree of automation so as to minimize the need for operator action in response to design basis events. All ESBWR automatic actions function as designed.

- The majority of operator actions in both the MCR and the RSS employ software based alarms, displays, and controls.
- Fixed position alarms, displays, and controls are available at a fixed location (or locations) but are not necessarily continuously displayed.
- Fixed position alarms, displays, and controls that are not continuously displayed are quickly and easily retrievable, typically accessible by one operator action (one touch accessible).
- An alarm is a visual or audible cue designed to capture an operator's attention and communicate information of a cautionary or warning nature that alerts the operator to the need to take manual actions or verify automatic actions. ESBWR minimum inventory alarms may consist of a visual cue, audible cue, or both.
- An event resulting in the evacuation of the MCR is not expected to occur in conjunction with any other design basis event. The RSS provides the capability to achieve and maintain safe stable shutdown conditions with the ESBWR systems functioning as designed.
- The ESBWR can be maintained in safe, stable shutdown for an indefinite period using passive safety systems. ESBWR technical specifications recognize "Stable Shutdown Mode" as an acceptable stable, safe shutdown condition with plant temperatures at or below 215.6°C (420°F).
- For the purpose of determining the RSS minimum inventory, operators successfully scram the reactor prior to leaving the MCR (ESBWR Design Control Document Chapter 15 MCR evacuation analysis).

18.5.1.2 **Process**

Functional Analysis

Substantial industry functional and task analysis over many years has gone into the creation of the BWR Owners' Group Emergency Procedure and Severe Accident Guidelines, Revision 2 (Reference 18.5-3) document. This analysis has resulted in the high level emergency operating procedure guidelines that are applied by industry BWRs.

The detailed plant design required to draft an ESBWR specific EPG was not complete at the time minimum inventory HSIs were specified. Because of this, the strategies, steps, and actions of Reference 18.5-3 were evaluated in the context of the ESBWR plant and systems design and operating strategies. Where the ESBWR design and operating strategies were similar to the designs that formed the basis of Reference 18.5-3, the guidance was implemented as recommended. Where the ESBWR design or operating philosophy differed from the Reference 18.5-3 basis reactors, a comparison between the Boiling Water Reactor Owners' Group (BWROG) guidance and ESBWR implementation was performed. The SAG strategies are not required for the development of minimum inventory.

This process is a functional analysis linking the strategy and task guidance contained in the BWROG document with the design specifics and system capabilities of the ESBWR.

Using the analytical approach presented in Chapter 19, design basis accident, event strategies, sequences, steps, and actions were evaluated. Any human actions included in these sequences were analyzed in the context of the ESBWR plant and systems design and operating strategies to determine error probabilities and consequences and risk-important human actions were identified. The human actions that were analyzed for minimum inventory support are those operator actions that would contribute greater than or equal to 10% of the NRC Safety Goals (e.g., Core Damage Frequency 1E-4/year, Large Release Frequency 1E-6/year) if not completed successfully. These actions are identified as the operator actions having the highest risk importance in Table 19.2-3.

The process used to identify risk-important human actions for the minimum inventory was an analytical functional analysis linking the ESBWR operating and accident mitigation strategies with the specific design and system capabilities of the ESBWR. Those human actions determined to be risk-important constitute the elements for which task analysis determined minimum inventory HSI requirements.

Task Analysis and HSI Requirements Determination

Task analysis processed the function and task elements assigned to operators to determine the alarms, displays, and controls needed to meet plant design goals and requirements.

Analysts evaluated operator MCR actions within the scope of the minimum inventory process and identified, prioritized, and organized plant and system tasks. RSS operator actions were evaluated within the context of the design basis MCR evacuation scenario and assumptions. The analysis context attributes provided by these documents include:

- System function priorities
- Direction for user focus
- Plant and system task sequences
- Task conditions, priorities, sequences, and initiation relationships
- Successful task completion criteria

Differing combinations of alarms, displays, and/or controls were assigned depending upon whether the analyzed element's emphasis was upon alerting, monitoring, diagnosing, and/or operating equipment in response to an event.

During the task analysis of the elements described above, minimum inventory HSIs were designated if they met the following selection criteria:

- HSIs that provide for the implementation of the Emergency Operating Procedures. When evaluating the need for plant manipulations, the criteria of the sub-bullets below were applied in the order provided. If support for the step was provided by the first criterion, then the second

criterion was not applied. This method resulted in the “primary” mitigating function(s) being selected for steps that contain multiple options.

1. HSIs that provide dedicated safety system actuation such as reactor scram, main steam isolation valve isolation, and ATWS response initiation.
2. HSIs that provide for assessing, accomplishing, or maintaining safety functions and safe shutdown conditions. For this criterion, HSIs to support plant manipulations were provided only if there was no automatic control.

- HSIs that provide for the performance of risk-important human actions as identified in the ESBWR PRA.
- HSIs that provide for achieving and maintaining safe, stable shutdown from the RSS following a design basis MCR evacuation event.

Analysts evaluated each human action within the context of the task sequence containing it (for example: an implementation action analysis considers the goals of the strategy being implemented and any preceding steps). Minimum inventory was compiled for:

- HSIs needed to prompt action
- HSIs needed to support decision making
- HSIs needed to support plant manipulations
- HSIs needed to support monitoring task success criteria

For the HSIs identified, analysts assigned one or more of the following types of minimum inventory:

- Alarms – Alert the operator regarding abnormal or degrading conditions that require operator response.
- Displays – Provide information necessary during task performance.
- Controls – Provide the means to change the state of plant equipment.

The design requirement for the minimum inventory HSIs is that they be accessible by one operator action (one touch accessible). Minimum inventory HSIs that are continuously displayed meet the one touch accessible design requirement. The one touch accessible design requirement for the minimum inventory HSIs is acceptable because of the passive nature of the ESBWR safety systems and the resultant required operator response times. Chapter 15 Design Basis Events require operator response times ranging from 30 minutes to, more typically, no operator response required or an operator response is not credited for 72 hours.

The result of this analysis is the ESBWR MCR and RSS minimum inventory of HSIs documented in Tables 18.1-1a and 18.1-1b.

18.5.2 Task Analysis Implementation Plan – Detailed Design

The TA implementation plan, Reference 18.5-2, establishes a task analysis process that conforms to ESBWR plans and applicable regulatory requirements. The process includes the design, detailed, and economic phases of task analysis as described in the plan. The system-level and plant-level functions are systematically analyzed. The relationships and interaction between human and machine tasks are examined through several iterations of analysis. TA considers all functions identified by the FRA and allocated to human, machine, or shared ownership.

18.5.2.1 Scope of Task Analysis

The TA Implementation Plan establishes the following scope elements.

1. Objectives, performance requirements, and constraints are defined.
2. Methods and criteria for conducting the TA are in accordance with accepted human factors principles and practices.
3. System and function requirements define task sequencing and coordination restraints.
4. TA results establish systems HSI requirements.
5. TA scope defines responsiveness to HRA/PRA and deterministic evaluations.
6. Task sequencing is established for each identified function.
7. Overall system configuration design is described.
8. Identifying and assigning types to accident monitoring instruments in accordance with RG 1.97.
9. TA scope includes the full range of plant conditions.

18.5.2.2 Methods of Task Analysis

The TA Implementation Plan establishes methods to:

1. Conduct the TA consistent with accepted HFE methods.
2. Promote the ESBWR mission, goals, and philosophy.
3. Identify prerequisites to performing a task or task sequence.
4. Identify the parameters required to coordinate tasks and task sequences.
5. Identify the termination criteria to abort a task or task sequence.
6. Identify the parameters that confirm successful completion of tasks or task sequences.
7. Identify and type accident monitoring instruments in accordance with RG 1.97.
8. Sequence tasks to support normal operation.
9. Sequence tasks to support abnormal operation.
10. Sequence tasks to support surveillance functions.

11. Sequence tasks to support maintenance functions.
12. Assess the impact of design, staffing, training, procedure, and HSI changes on the sequence and coordination of tasks.

18.5.2.3 Results of Task Analysis

The results of the TA activity are summarized in a RSR. The content of the TA RSR is described in Reference 18.5-2. TA RSR may be combined with the FRA or AOF RSRs.

18.5.3 COL Information

None.

18.5.4 References

18.5-1 *GE Hitachi Nuclear Energy, "ESBWR Man-Machine Interface System and Human Factors Engineering Implementation Plan," NEDE-33217P, Class III (Proprietary), Revision 6, February 2010, and NEDO-33217, Class I (Non-proprietary), Revision 6, February 2010.*

18.5-2 *GE Hitachi Nuclear Energy, "ESBWR Human Factors Engineering Task Analysis Implementation Plan," NEDE-33221P, Class III (Proprietary), Revision 4, February 2010, and NEDO-33221, Class I (Non-proprietary), Revision 4, February 2010.*

18.5-3 BWR Owners' Group Emergency Procedures Committee, "BWR Owners' Group Emergency Procedure and Severe Accident Guidelines," Revision 2, March 2001.

18.6 Staffing and Qualifications

The S&Q process is conducted in accordance with References 18.6-1 and 18.6-2.

18.6.1 Background

Plant staffing levels and plant staff qualifications are important considerations throughout the design process. Initial staffing level is established based on experience with predecessor plants, staffing goals, initial analyses, and regulatory requirements. ESBWR staffing and qualifications plans systematically re-examine predecessor plant assumptions and consider staffing reductions warranted by the use of passive safety systems.

18.6.2 Objectives and Scope of Staffing and Qualifications Analyses

The objectives of the staffing and qualifications analyses and the scope of the analyses performed are provided in Reference 18.6-2. The scope includes the number and qualifications of personnel for the full range of plant conditions and tasks including operational tasks (normal, abnormal, and emergency); plant maintenance and testing; and surveillance testing. The staff considered in the scope for the staffing and qualifications analyses meets requirements defined in 10 CFR 50.54 and the categories of personnel defined by 10 CFR 50.120. They include: licensed operators, non-licensed operators, shift supervisor, shift technical advisor, instrument and control technicians, electrical and mechanical maintenance personnel, radiological protection technicians, chemistry technicians, and engineering support personnel. In addition, all other plant personnel who perform tasks that are directly related to plant safety are also addressed.

18.6.3 ESBWR Baseline Staffing Assumptions

The staffing assumption for an ESBWR unit is depicted in Table 18.6-1 and consists of the onsite staffing by operators and senior operators licensed under 10 CFR 55.

A licensed operator remains in control of plant operation during all states of operation. During normal operations the operator at the controls monitors the automated control functions. The operator at the controls is able to assume manual control of those functions that have been automated for reasons other than regulatory requirements. The operating crew's training includes manual operation of an automated function that has been returned to manual monitoring and control.

18.6.4 Staffing and Qualifications Plan

The HFE team develops a staffing analysis plan, Reference 18.6-2, to perform an iterative HFE implementation process in accordance with Figure 18.1-1 and Reference 18.6-1*.* The basis for the staffing and qualifications plan addresses the following issues.

18.6.4.1 **Operating Experience Review**

Operating experience review provides the following inputs for staffing and qualifications analyses:

- Operational problems and strengths that resulted from staffing levels in predecessor plant systems.
- Initial staffing goals and their bases including staffing levels of predecessor plants.
- Systems and a description of significant similarities and differences between predecessor plant systems and ESBWR 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."

18.6.4.2 **Functional Requirements Analysis and Function Allocation**

Functional requirements analysis and function allocation provide the following inputs for staffing and qualifications analyses:

- Functions allocated to personnel
- Changes in the roles of personnel due to plant system and HSI modifications

18.6.4.3 **Task Analysis**

Task analysis provides the following inputs for staffing and qualifications analyses:

- Knowledge, skills, and abilities needed by personnel as identified by the task analysis.
- Personnel response time and workload.
- Personnel communication and coordination, including interactions among them for diagnosis, planning, and control activities, and interactions among personnel for administrative, communications, and reporting activities.
- Job requirements resulting from the sum of all tasks allocated to each individual both inside and outside the control room.
- Impact on the ability of personnel to perform their function due to plant and HSI modifications.
- Availability of personnel considering other ongoing activities.
- Assignment of operators to tasks outside the control room (for example, fire brigade).
- Actions identified in 10 CFR 50.47, NUREG-0654, and procedures to meet an initial plant accident response in key functional areas as identified in the emergency plan.
- Staffing considerations described by the application of ANSI/ANS 58.8-1994, R2001, "Time Response Design Criteria for Safety-Related Operator Actions" (Reference 18.6-3).

18.6.4.4 Human Reliability Analysis

HRA provides the following inputs for staffing and qualifications analyses:

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

18.6.4.5 Human-System Interface Design

HSI Design provides the following inputs for staffing and qualifications analyses:

- Staffing demands resulting from the locations and use (especially concurrent use) of controls and displays.
- Coordinated actions among individuals.
- The availability or accessibility of information needed by personnel due to plant system and HSI modifications.
- The physical configuration of the control room and control consoles.
- The availability of plant information from individual workstations and group-view interfaces.

18.6.4.6 Procedure Development

Procedure development provides the following inputs for staffing and qualifications analyses:

- Staffing demands resulting from requirements for concurrent use of multiple procedures
- Personnel skills, knowledge, abilities, and authority identified in procedures

18.6.4.7 Training Program Development

Crew coordination issues are identified during the development of training.

18.6.5 Methodology of Staffing and Qualifications Analyses

The S&Q analyses methodology is coordinated with Section 13.1, and is related to organization and staffing. The staffing analysis is iterative and the initial staffing goals are reviewed and modified as the analyses associated with other HFE elements are completed. The staffing plan supports Section 13.1 to address compliance with 10 CFR 50.54 (i) through (m).

Additional methodology for the staffing and qualifications element is provided in the S&Q Implementation Plan described in Reference 18.6-2.

18.6.6 Results of Staffing and Qualifications Analyses

The results of the S&Q activity are summarized in a RSR. The content of the S&Q RSR is described in Reference 18.6-2.

18.6.7 COL Information

None.

18.6.8 References

18.6-1 *GE Hitachi Nuclear Energy, "ESBWR Man-Machine Interface System and Human Factors Engineering Implementation Plan," NEDE-33217P, Class III (Proprietary), Revision 6, February 2010, and NEDO-33217, Class I (Non-proprietary), Revision 6, February 2010.*

18.6-2 *GE Hitachi Nuclear Energy, "ESBWR Human Factors Engineering Staffing and Qualifications Implementation Plan," NEDO-33266, Class I (Non-proprietary), Revision 3, January 2010.*

18.6-3 American National Standards Institute, "Time Response Design Criteria for Safety-Related Operator Actions," ANSI/ANS 58.8-1994, August 1994, R2001.

Table 18.6-1 ESBWR Staffing Assumptions

Quantity	Qualifications	Assignment
1	Control Room Supervisor[(1)]	Provides overall supervision of control room operations.
2	Reactor Operators[(2)]	First operator is assigned to normal control actions at MCR HSI. Second operator is assigned to control of testing, surveillance and maintenance activities, including blocking and tagging permits.
1	SRO (Shift Manager)[(1)]	Assigned to shift but not necessarily in the MCR. Acts as manager of and relief for shift supervisor.
2	Auxiliary Operators[(3)]	Qualified to operate equipment in the plant.

Notes:

1. Licensed by the NRC as a Senior Reactor Operator (SRO)
2. Licensed by the NRC
3. Non-licensed, often called Auxiliary Equipment Operators (AEOs)

18.7 Human Reliability Analysis

The HRA process is conducted in accordance with References 18.7-1 and 18.7-2, and as a part of a PRA for both pre- and post-initiator human actions.

18.7.1 Objectives and Scope of Human Reliability Analysis

Reference 18.7-1 describes how the HFE program uses the HRA. An initial “design level” ESBWR PRA to support NRC certification and the performance of the HRA quantification is addressed in Chapter 19. Managing the impact of potentially risk-important human interactions and human-error mechanisms through the HSI design is the scope of this section.

The scope for using HRA in HFE activities includes:

1. A listing of potentially risk-important human interactions for operating the ESBWR.
2. An assessment of the potentially risk-important human interactions to establish a list of risk-important HAs.
3. Analysis of the potential for and mechanisms of human error that may affect plant safety, particularly the potentially risk-important HAs.
4. An evaluation of potential human errors in the design of HFE aspects of the plant to address the likelihood of personnel error, detect errors and recover from them, and determine if new or modified HSI design features are needed to reduce the likelihood and impact of errors.
5. Updating the PRA with HRA results and integrating the PRA insights into the HFE program.

18.7.2 Methodology of Human Reliability Analysis

The ESBWR design process uses three methods for identifying potentially risk-important human interactions. These are (1) PRA evaluation (ESBWR and predecessor plant PRAs), (2) operational analysis, and (3) personal observation either during simulator tests or gleaned from operating experience event reports.

The initial PRA/HRA results and the potentially risk-important human interactions are provided to the HFE team to analyze and identify risk-important HAs. Risk-important HAs are explicitly addressed in the operational analysis (FRA, AOF and TA). The results of the operational analyses are used to refine the HRA input to the PRA.

The results of the PRA/HRA are used by the HFE design team (through HSI design, procedural development, and training) to reduce the likelihood of operator error and provide for error detection and recovery capability to ensure the potentially risk-important HAs do not exceed the importance measure thresholds. For example, the means for reducing human interaction importance for operator actions found in predecessor BWRs include the use of passive cooling systems, increased automation, and computer-based HSIs that simplify the way that operators interact with the ESBWR compared with predecessor BWRs. Passive cooling eliminates the need for manually

operating and controlling forced cooling systems. The operators concentrate more on monitoring and determining a course of action.

The process for determining the risk-important human interactions includes the use of:

- Level 1 (core damage) design level PRAs
- Level 2 (release from containment) PRAs and post-core damage actions
- Internal and external events portions of the PRA
- The low power and shutdown PRA

The list of potentially risk-important human interactions is determined by applying two importance measures, Fussell-Vesely and risk achievement worth, to PRA results as described in Reference 18.7-2. The process for identifying the list of potentially risk-important human interactions through PRA modeling is described in Section 19.2.

The risk-important HAs are identified from the potentially risk-important human interactions as described in Reference 18.7-2.

During the HFE design process the HFE team verifies that HRA assumptions, such as decision-making and diagnosis strategies for dominant sequences, are valid and the potentially risk-important HAs can be performed using the HSI. The HFE design process verifies the HAs can be carried out using the HSI and procedures, the implementation interface, and other features identified in the PRA accident context during the HFE V&V activities.

The HFE descriptions and analyses of operator functions and task requirements become inputs to the HRA quantification model through the HRA model updates. The HRA assesses any manual actions operators are required to take for properly operating safety systems such as the Emergency Core Cooling System (ECCS).

HRA model updates replace initial PRA assumptions by using design information from the HFE operational analysis to define operator functions and task requirements from the analysis of plant and system functions.

The HRA model updates previous PRA-identified actions and errors with elements for performance factors associated with the operational characteristics of HSI design, procedures for normal, startup, shutdown, and emergency operations, as well as training programs.

18.7.3 **Results of Human Reliability Analysis**

The results of the HRA activity are summarized in a RSR. The content of the HRA RSR is described in Reference 18.7-2.

18.7.4 **COL Information**

None.

18.7.5 References

18.7-1 *GE Hitachi Nuclear Energy, "ESBWR Man-Machine Interface System and Human Factors Engineering Implementation Plan," NEDE-33217P, Class III (Proprietary), Revision 6, February 2010, and NEDO-33217, Class I (Non-proprietary), Revision 6, February 2010.*

18.7-2 *GE Hitachi Nuclear Energy, "ESBWR Human Factors Engineering Human Reliability Analysis Implementation Plan," NEDO-33267, Class I (Non-proprietary), Revision 4, January 2010.*

18.8 Human-System Interface Design

The HSI process is conducted in accordance with References 18.8-1 and 18.8-2.

The primary areas of human interface are the ESBWR MCR, RSS, TSC, EOF, and LCSs with safety-related functions or identified through task analysis. The results of HSI efforts are summarized in the HSI RSR and are available for the conformance reviews.

The Human Performance Monitoring (HPM) activity described in Section 18.13 addresses the HSI change process, after the plant is in operation, by which:

- HSIs are modified and updated.
- Temporary HSI changes are made.
- Operator defined HSIs are created (as temporary displays defined by operators for monitoring specific plant situations).
- The procedures governing permissible operator initiated changes to HSIs are described.

18.8.1 Human-System Interface Design Implementation Plan

The HSI Design Implementation Plan, Reference 18.8-2 is comprised of three technical sections.

1. The HSI Concept Design establishes:
    a. Methods and criteria for HSI equipment design and evaluation of HSI human performance, equipment design, and associated work place factors, (e.g., illumination, noise, and ventilation) consistent with accepted HFE guidelines, principles, and methods.
    b. Information and control requirements, including the displays, controls, and alarms necessary for the execution of identified tasks.
    c. Methods for comparing the consistency of the HSI human performance equipment, design, and associated workplace factors as modeled and evaluated in the completed task analysis.
    d. Equipment (hardware and software) functions as determined in the task analysis.
2. The HSI Specific Guidance incorporated in the ESBWR Style Guide addresses:
    a. Identification of the specific HFE standards and guidelines documents.
    b. Substantiation that selected HSI design evaluation methods and criteria are based upon accepted HFE practices and principles.
    c. Definition of standardized HFE design conventions.
    d. Criteria for verification that the design features; the HSI equipment technologies; and the displays, controls, and alarms are incorporated.

e. Design input to the definition of the design/evaluation tools (for example, prototypes) which are to be used in the conduct of the HSI design analyses, the specific scope of evaluations for which those tools are to be applied, and the rationale for the selection of those specific tools and their associated scope of application.

3. The HSI Detailed Design and Integration establishes:

   a. Design criteria and guidance for control room operations during periods of maintenance, test, and inspection of control room HSI equipment and human interfaces.

   b. Test and evaluation methods for resolving HFE/HSI design issues. These include the criteria to be used in selecting HFE/HSI design and evaluation tools which:

      - Incorporate the use of static mockups and models for evaluating access and workspace-related HFE issues.

      - Require dynamic simulations and HSI prototypes for conducting evaluations of the human performance associated with the activities in the critical tasks identified in the task analysis.

18.8.2 Results of Human-System Interface Design

The results of the HSI activity are summarized in a RSR. The content of the HSI RSR is described in Reference 18.8-2.

18.8.3 COL Information

None.

18.8.4 References

18.8-1 *GE Hitachi Nuclear Energy, "ESBWR Man-Machine Interface System and Human Factors Engineering Implementation Plan," NEDE-33217P, Class III (Proprietary), Revision 6, February 2010, and NEDO-33217, Class I (Non-proprietary), Revision 6, February 2010.*

18.8-2 *GE Hitachi Nuclear Energy, "ESBWR Human Factors Engineering Human-System Interface Design Implementation Plan," NEDE-33268P, Class III (Proprietary), Revision 5, February 2010, and NEDO-33268, Class I (Non-proprietary), Revision 5, February 2010.*

18.9 Procedure Development

The procedure development process is conducted in accordance with References 18.9-1 and 18.9-2 and coordinated with the procedure development described in Section 13.5.

Procedures are essential to plant safety because they support and guide personnel interactions with plant systems and their response to plant-related events.

The HFE team generates the implementation plan for procedure development, Reference 18.9-2, which addresses the applicable guidance from NUREG-0800. The reference ESBWR normal operating, abnormal operating, and emergency operating procedures are developed as an integral part of the MMIS and HSI development as described in Reference 18.9-1. The ESBWR procedure process addresses personnel tasks affected by the changes in plant systems and HSIs. Procedures are developed or modified to reflect the characteristics and functions of the plant improvements. The same human factors principles applied to all aspects of the HSI verify complete integration and consistency.

Reference 18.9-1 describes the process to verify functions and tasks linked to the plant procedures in the task analysis are included in the operating procedures. The process includes validation of the operating procedures using the mockup/part-task and full-scope simulator facility.

Procedures are presented electronically and are available in hard copy. The procedures are written to HFE best practices to establish the following attributes:

- Presented as logic or flow charts (where practical)
- Displays include decision-making aids and requisite steps
- Checklist of prerequisites or interlocks to steps
- Allow operator access to controls
- Verification of operator decisions
- Retention of operator control and authority
- Logging of decisions
- Continuous update of plant parameters and plant status

18.9.1 **Objectives and Scope of Procedure Development**

The objective of the procedure development activity is to provide the process, methods, and criteria for generating procedures and verifying integrated plant procedures are consistent with accepted HFE practices and principles. The scope of the procedures addressed in this section is:

- EOPs including generic technical guidelines for EOPs
- Plant and system operations (including startup, power, and shutdown operations)
- Test and maintenance

- Abnormal and emergency operations
- Alarm response

18.9.2 Methodology of Procedure Development

Activities under this subsection are coordinated with the procedures development described in Section 13.5. Reference 18.9-2 describes the basis for procedure development including:

- Plant design bases
- System-based technical requirements and specifications
- Task analyses results
- Risk-important HAs identified in the HRA/PRA
- Initiating events to be considered in EOPs, including those events in the design basis
- Generic technical guidelines for EOPs

The ESBWR HFE Procedures Development Implementation Plan (Reference 18.9-2) describes how the procedures program addresses the requirements specified in 10 CFR 50.34(f)(2)(ii) and describes the Procedure Writers' Guide. The Procedure Writers' Guide establishes the process for developing technical procedures that are complete; accurate; consistent; and easy to understand and follow. In addition, the plan provides details about the following topics:

- Writer's Guide: How the writer's guide ensures procedures are consistent in organization, style, and content; and which procedures fall within the purview of the guide.
- Procedure Format: The basic content and format used for procedures in the facility.
- EOPs: The logic used in developing the content of generic technical guidelines and EOPs, for example, symptom-based procedures with clearly specified entry conditions.
- Procedures V&V: The procedure verification & validation program including the use of simulation.
- Computer-based Procedures: The process for the development, V&V, and implementation of computer-based procedures includes a description of the HSI for the computer-based procedures. An analysis of the available alternatives in the event of loss of computer-based procedures is also provided.
- Procedure Maintenance: The process for procedure maintenance and control of updates after the plant is in operation is addressed in programs established in the Human Performance Monitoring (HPM) activity described in Section 18.13. This process is integrated across the full set of procedures and ensures that alterations in particular parts of the procedures are consistent with other parts of the full set of procedures.
- Procedure Access and Use: How operators access and use procedures, especially during operational events, for both hard copy and computer-based procedures.

18.9.3 Results of Procedure Development

The results of the procedure development activity are summarized in a RSR. The content of the procedure development RSR is described in Reference 18.9-2.

18.9.4 COL Information

None.

18.9.5 References

18.9-1 *GE Hitachi Nuclear Energy, "ESBWR Man-Machine Interface System and Human Factors Engineering Implementation Plan," NEDE-33217P, Class III (Proprietary), Revision 6, February 2010, and NEDO-33217, Class I (Non-proprietary), Revision 6, February 2010.*

18.9-2 GE Hitachi Nuclear Energy, "ESBWR Human Factors Engineering Procedures Development Implementation Plan," NEDO-33274, Class I (Non-proprietary), Revision 5, February 2010.

18.10 Training Program Development

The training program development process is conducted in accordance with References 18.10-1 and 18.10-2 and coordinated with the training development described in Section 13.2. Training of plant personnel is an important factor in ensuring safe and reliable operation of nuclear power plants. The training program provides reasonable assurance plant personnel have the knowledge, skills, and abilities to properly perform their roles and responsibilities.

18.10.1 Purpose

The purpose of the implementation plan for training program development is to systematically incorporate information from the other HFE design tasks to support implementation of ESBWR personnel training. As a minimum the training program includes the following activities:

- A systematic analysis of the tasks and jobs that are triggered by cues from the HSI or procedures.
- Development of learning objectives derived from an analysis of desired performance through the training program.
- 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.

18.10.2 Scope of Training Program Development

The overall scope of training includes the following:

- Categories of personnel to be trained, including the full range of positions for operational personnel including licensed and non-licensed personnel whose actions may affect plant safety.
- The full range of plant conditions (normal, abnormal, and emergency).
- Specific operational activities (for example, operations, calibrations, inspections, and testing).
- The full range of plant functions and systems.
- The full range of relevant HSIs (for example, MCR, RSS, and LCSs with a safety-related function or as defined by task analysis, TSC & EOF interface).

18.10.3 Methodology of Training Program Development

The activities in this section are coordinated with Section 13.2 and address how the training program follows a systematic approach to address the requirements of 10 CFR 50.120, 10 CFR 52.78, and 10 CFR 55.

The roles of all organizations, especially the HFE team, are specifically defined for the development of training requirements, development of training materials, and implementation of the training

program. For example, the role of the vendor may range from merely providing input materials (for example, generic technical guidelines) to conducting portions of specific training programs. The qualifications of organizations and personnel involved in the development and conduct of training are defined.

Facilities and resources such as a training simulator needed to satisfy training design requirements and the guidance contained in ANSI 3.5 (Reference 18.10-3) and Regulatory Guide 1.149 are defined.

The analyses approach to derive the learning objective includes the use of:

- The licensing basis
- Operating experience
- Function analysis and allocation
- Task analysis, human reliability analysis
- The details of the HSI design
- Plant procedures
- Insights from the V&V

The development of learning objectives describes what knowledge and skill attributes must be successfully learned.

The training program includes the use of lectures, simulators, and computer-based training; training on theory and practical applications; and schedule, timing, and arrangement of training.

18.10.4 **Elements for Training Program Development**

The following elements are supported by the HFE design team to develop the general approach, organization of training, learning objectives, content of training program, evaluation of training, and periodic re-training.

18.10.4.1 **General Approach**

A systematic approach to the training of plant personnel is developed.

The approach follows applicable guidance in NUREG-0800 Section 13.2 (“Training”), as defined in 10 CFR 55.4, and as required by 10 CFR 52.78 and 10 CFR 50.120. The overall scope of training defined and supported by the HFE design team, includes the following elements:

- Categories of personnel to be trained (for example, SRO).
- Specific plant conditions (normal, abnormal, and emergency).
- Specific operational activities (for example, operations, calibrations, inspections, and testing).
- Key actions as required by cues from the HSIs (for example, in the MCR, TSC, EOF, RSS and LCSs).

The training program plan provides reasonable assurance that personnel have the qualifications commensurate with the performance requirements of their jobs. The training program addresses:

- A full range of positions of operational personnel including licensed and non-licensed personnel whose actions may affect plant safety.
- A full range of plant functions and systems including those that may be different from those in predecessor plants (for example, passive systems and functions).
- A full range of relevant HSIs (for example, display space navigation, operation of “soft” controls) within applicable scope (i.e., MCR, RSS, TSC, EOF, LCSs) as is appropriate for each job classification.

18.10.4.2 **Organization of Training**

The training plan defines the specific roles for development of training requirements, information sources, materials, and the roles for implementation of the training program. The HFE team provides input materials to the training program as requested to develop and deliver specific training modules.

The qualifications of organizations and personnel involved in the development and conduct of training is defined in the training plan.

Resources such as part-task, full-scope, and training simulators are utilized in the ESBWR HFE implementation process for both design verification and training. These facilities and resources include features of the HSI that are based on the inputs of the HFE team.

18.10.4.3 **Learning Objectives**

Learning objectives for each job description are derived from the analysis and information from the HFE team that describe desired performance after training. This analysis includes but is not limited to training needs identified in the following elements:

- Licensing – Final safety analysis report, system description manuals and operating procedures, facility license and license amendments, licensee event reports, and other documents identified as being important to training.
- Operating Experience Review – Previous training deficiencies and operational problems that can be corrected through additional and enhanced training, and positive characteristics of previous training programs.
- Function Analysis and Allocation – Functions identified by the HFE design team.
- Task Analysis – Tasks identified through the HFE process as posing unusual demands including new or different tasks, and tasks requiring a high degree of coordination, high workload, or special skills.
- Human Reliability Analysis – This analysis as part of the PRA/HRA provided by the HFE design team defines coordinated roles for the operational crew to reduce the likelihood and/or

consequences of human error associated with risk-important HAs and the use of advanced technology. Generic design PRA/HRA models are plant specific.

- HSI Design – The HFE design team identifies HSI features whose purpose or operation is different from the past experience or expectations of personnel. This is vitally important in the areas where an expanded role for passive safety systems has been incorporated into the defense in depth safety functions.
- Procedure Development – The basic BWR symptom-based emergency procedures are referenced as a pattern by the HFE team. The HFE team addresses specific tasks that have under gone extensive revision during past procedure development to address plant safety concerns.
- Verification and Validation – The HFE design team provides scenarios and information to support V&V testing and adjust training based on evaluation and feedback.

Learning objectives for personnel training address the knowledge and skill attributes associated with all relevant topics. The HFE design team develops dimensions of a trainee's job requirements. Table 18.10-1 illustrates generic learning objectives for interactions with the plant, the HSIs, and other personnel.

18.10.4.4 **Content of Training Program**

The training program follows a systematic approach described in the Training Development Implementation Plan, Reference 18.10-2. The training implementation plan includes:

- Methods to convey learning objectives
- Application of classroom simulators, and on-the-job training methods
- Catalogue of specific plant conditions and scenarios
- Specific training scenarios based on lessons learned
- Organization and schedule of training modules
- Development of simulator scenarios to demonstrate continued proficiency
- Operational knowledge intended to teach skill elements within the context of actual job tasks
- Strategies to maintain situational awareness and operator vigilance
- Skills requiring response to off-normal conditions that affect automation

Systematic training develops skills built upon operational precepts. For example, trainees master the manipulation of control devices through the HSI before developing coordination skills among crewmembers that require knowledge of how to manipulate the control system.

The training program employs the symptom-based procedures developed to support rules for decision-making related to plant systems, HSIs, and use of the procedures. The symptom-based procedures include rules for identifying cues, and confirming and interpreting information. The

training program encompasses decision-making rules for interpreting symptoms of failures of systems, HSIs, and procedures that are a direct result of the passive design.

18.10.4.5 **Evaluation and Modification of Training**

The training program plan includes methods for evaluating the overall effectiveness of the training programs and trainee mastery of training objectives, including written tests and oral tests and observation of personnel performance during walk-through, simulator exercises, and while on-the-job. Evaluation criteria for mastery of training objectives during individual training modules are defined in the training program plan. Methods for assessing overall proficiency are defined and coordinated with regulations, where applicable for licensed personnel.

The training program plan defines methods for verifying the accuracy and completeness of training course materials.

The training program plan establishes procedures for refining and updating the content and conduct of training in collaboration with the programs established in the HPM activity for the maintenance and update of the training program after the plant is in operation. The plan includes provisions for tracking training course modifications.

18.10.4.6 **Periodic Retraining**

The training program plan addresses how often and which job classifications need to undergo periodic retraining. The training program plan provides for evaluating whether any changes in training are warranted following plant upgrades and other modernization programs.

18.10.5 **Results of Training Program Development**

The results of the training program development activity are summarized in a RSR. The content of the training program development RSR is described in Reference 18.10-2.

18.10.6 **COL Information**

None.

18.10.7 **References**

18.10-1 *GE Hitachi Nuclear Energy, "ESBWR Man-Machine Interface System and Human Factors Engineering Implementation Plan," NEDE-33217P, Class III (Proprietary), Revision 6, February 2010, and NEDO-33217, Class I (Non-proprietary), Revision 6, February 2010.*

18.10-2 GE Hitachi Nuclear Energy, "ESBWR Human Factors Engineering Training Development Implementation Plan," NEDO-33275, Class I (Non-proprietary), Revision 4, January 2010.

18.10-3 American National Standards Institute, "Nuclear Power Plants Simulators for Use in Operator Training and Examination," ANSI/ANS 3.5-1998, April 1998.

Table 18.10-1 Example 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 Control Room[1] and in the plant)	Understanding information requirements of others, how actions will be coordinated with others, policies and constraints on crew's interaction.	Skills associated with crew interactions (that is, teamwork).

(Excerpted NUREG 0711, Rev 2 Table 10.1)

Note:

1. Control Room was spelled out instead of using CR from the original. CR is used as an acronym for Control Rod.

18.11 Human Factors Verification and Validation

The HFE V&V process is conducted in accordance with References 18.11-1 and 18.11-2. This section describes the six main activities of HFE V&V:

1. HSI inventory and characterization
2. HSI task support verification
3. HFE design verification
4. Operational condition sampling
5. Integrated system validation
6. Human engineering discrepancy resolution

18.11.1 Human Factors Verification and Validation Implementation

The ESBWR HFE Verification and Validation Implementation Plan, Reference 18.11-2, establishes:

1. Human factors V&V methods and criteria consistent with accepted HFE practices and principles.
2. The scope of the evaluations of the HSI including:
    a. The interface of the operator with the HSI equipment hardware and the interface of the operator with the HSI equipment’s software-driven functions.
    b. Plant operating procedures.
    c. HSI work environmental conditions.
    d. Aspects of the HFE design process that impact human interface with the HSI including procedures, training, and staffing and qualification.
3. The process for producing a characterized list of HSIs that accurately describes the HSI alarms, controls, indications, and related equipment to be verified.
4. The process for verifying that the characterized inventory of HSI equipment implementing the alarm, control, and indication requirements identified in the task analyses are designed per accepted HFE guidelines and principles.
5. The process for verifying that the HSI equipment providing the alarms, controls, and indications supporting the performance of tasks meets the personnel task performance requirements identified in task analysis.
6. The process for identifying and selecting operational conditions to be incorporated into V&V.
7. The process for validating that the integrated system design acceptably supports the safe and efficient operation of the plant.
8. The process by which human engineering discrepancies are identified and resolved.
9. The process for documenting and retaining the detailed verification and validation results.

18.11.2 Results of Human Factors Verification and Validation

The results of the HFE V&V activity are summarized in a RSR. The content of the HFE V&V RSR is described in Reference 18.11-2.

18.11.3 COL Information

None.

18.11.4 References

18.11-1 *GE Hitachi Nuclear Energy, "ESBWR Man-Machine Interface System and Human Factors Engineering Implementation Plan," NEDE-33217P, Class III (Proprietary), Revision 6, February 2010, and NEDO-33217, Class I (Non-proprietary), Revision 6, February 2010.*

18.11-2 *GE Hitachi Nuclear Energy, "ESBWR Human Factors Engineering Verification and Validation Implementation Plan," NEDE-33276P, Class III (Proprietary), Revision 4, February 2010, and NEDO-33276, Class I (Non-proprietary), Revision 4, February 2010.*

18.12 Design Implementation

The design implementation process is conducted in accordance with References 18.12-1 and 18.12-2. The Design Implementation Plan, Reference 18.12-2, addresses the final "as-built" implementation of the HFE plant design for new plants constructed using the ESBWR standard plant. The HFE aspects of the ESBWR standard plant including design of the HSIs, standard plant procedures, and baseline training documentation are verified and validated during the HFE V&V process.

18.12.1 **Objectives and Scope of Design Implementation**

The ESBWR HFE Design Implementation Plan has the following objectives:

- Confirm that the final HSIs, procedures and training (as-built) HFE design conforms to the ESBWR standard plant design HSI, Procedures, and Training Requirements as defined in Reference 18.12-2.
- Verify aspects of the design and any physical or environmental (for example, noise, lighting, and so forth) differences between those present at the V&V process and the "as-built" MCR.
- Verify resolution of remaining human engineering discrepancies (HEDs) and open items from the Human Factors Engineering Issue Tracking System (HFEITS).
- Transfer responsibility for HFEITS.

The "as-built" confirmations, verifications, and validations described in the Design Implementation Plan apply to the combined license (COL) plants constructed using the ESBWR standard plant design. The ESBWR standard plant design against which the "as-built" comparison is made is derived from the revised HSI design and the standard plant procedures and training documents and established as the HSI, Procedures, and Training requirements in Reference 18.12-2. These include the corrections and improvements from the HFE V&V process.

18.12.2 **Methodology of Design Implementation**

18.12.2.1 **Human-System Interface Verification (As-Built)**

The HSIs and their design characteristics are established in the HSI design activity using the guidance in the ESBWR Style Guide and summarized in the HSI RSR. The HSIs are subsequently evaluated and confirmed in the HFE V&V. Following the HFE V&V, the inventory of HSI and characteristics is revised and becomes the basis for the requirements and acceptance criteria for the verification of the equipment in the "as-built" installation. The process and the rationale for the HSI design are documented and managed under GE Hitachi Nuclear Energy Quality Assurance and ESBWR specific design program plans.

The "as-built" verification for the HSIs involves confirmation that the as-built HSI and their design characteristics correspond to the HSI requirements as described in Reference 18.12-2.

18.12.2.2 Procedures and Training Confirmation (As-Built)

The standard plant procedures and training documentation are established in development activities. The HFE V&V validates the adequacy of the proposed HSIs and the standard plant procedures and training to support personnel performance.

Some changes to the standard plant procedures and training may result from the HFE V&V. The approach to perform the "as-built" confirmation for the procedures and training is to conduct an audit of the as-built plant procedures and training.

18.12.2.3 Final HFE Design Verification Not Performed in the Simulated HFE V&V Activity

HFE design aspects that are not addressed in the simulated HFE V&V such as modification of the reference plant to the standard design, and HFE aspects not feasible to perform in the simulated environment are included in the Design Implementation activity. These include:

- Communication equipment interfaces (e.g., phones, radios, and intercoms).
- Lighting (normal and emergency).
- Habitability systems (e.g., noise, lighting, and ventilation).
- Use of plant-specific training manuals and procedures.
- Data and video interfaces with the TSC and equipment to duplicate or link the EOF to the plant process database.
- Procedure/piping and instrumentation drawing laydown area

18.12.2.4 Resolution of Remaining HEDs and Open Issues and Transfer of HFEITS

The HFE V&V of the standard plant design addresses the issues from the HFE design and development. The design implementation process is used to close out remaining issues from the MMIS/HFE implementation process. Reference 18.12-2 describes the transfer and the responsibilities for maintaining HFEITS.

18.12.3 Results of Design Implementation

The results of the design implementation activity are summarized in a RSR. The content of the design implementation RSR is described in Reference 18.12-2.

18.12.4 COL Information

None.

18.12.5 References

18.12-1 *GE Hitachi Nuclear Energy, "ESBWR Man-Machine Interface System and Human Factors Engineering Implementation Plan," NEDE-33217P, Class III (Proprietary), Revision 6, February 2010, and NEDO-33217, Class I (Non-proprietary), Revision 6, February 2010.*

18.12-2 *GE Hitachi Nuclear Energy, "ESBWR Human Factors Engineering Design Implementation Plan," NEDO-33278, Class I (Non-proprietary), Revision 4, January 2010.*

18.13 Human Performance Monitoring

The HPM process is conducted in accordance with References 18.13-1 and 18.13-2. The HPM strategy links human factors engineering methods used during the design with methods for monitoring human performance during operation.

18.13.1 Purpose

The purposes of HPM are:

- To ensure that the high safety standards established during the HSI design are maintained even when changes are made to the plant.
- To provide adequate assurance that the safety bases remain valid during the operational phase of the plant.

There is no intent to periodically repeat a full-integrated system validation. The strategy is to provide a monitoring plan; building upon the HFE activities during the design that can be carried forward into the operational phase, using industry accepted methods. HPM incorporates this monitoring strategy into the problem identification and corrective action program, which identifies and classifies human errors, provides for evaluation of the root cause, and supports effectiveness verification and documentation of the corrective action.

18.13.2 Human Performance Monitoring Strategy Development

The scope of the performance monitoring strategy provides reasonable assurance that:

- The HSI design is effective during:
    - Normal operations
    - Abnormal Operating Occurrences
    - Accidents
    - Design basis events
    - Significant industry events
    - Key scenarios identified by the PRA/HRA
- Human actions, using HSI information, cues and controls can accomplish critical tasks while maintaining margin for time and performance criteria.
- Acceptable performance levels established during the integrated HSI validation are maintained. The methods for evaluation and trending established for the plant operators through the Institute of Nuclear Power Operators' Human Performance Enhancement System provides an industry-accepted approach.
- Changes made to the initial HSIs, procedures, and training does not have adverse effects on personnel performance, for example, a change interferes with trained skills.

- The screening and processing discussed in Regulatory Guide 1.174 forms the basis of the documentation strategy and any links to the content in Chapter 18 for the updated final safety analysis report (UFSAR).

18.13.3 Elements of Human Performance Monitoring Process

HPM strategy includes consideration of:

- Data collection
- Importance screening
- Event analysis to determine causes
- Trend analysis
- Corrective action development
- Maintenance and control of updates for:
    - HRA/PRA
    - Function Requirements Analysis
    - Function Allocation
    - Staffing and Qualifications
    - HSI changes
    - Procedures
    - Training program
    - Personnel retraining

The HPM process draws upon existing information sources and programs to supplement the data collection.

The HPM strategy collects data to trend human performance. The data demonstrates consistency among implemented changes and assumptions. Assumptions are a result of initial design or HSI design changes. The strategy uses existing utility or industry programs (for example, corrective action programs or licensed operator training) for data collection. The HPM strategy ensures 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

This strategy is implemented through the use of a representative training simulator during periodic training exercises. The HSI design process assumes that a simulator is maintained and upgraded to match the actual control room with good interface and dynamic response fidelity (that is, per 10 CFR 55.49 and ANSI 3.5 [Reference 18.13-3]).

The HPM process maintains a database of event causes and corrective actions taken. Such data supports trending of performance anomalies.

The HPM process identifies and establishes corrective actions that reduce the potential for incident recurrence. The strategy systematically identifies the cause of the failure or degraded performance. The corrective actions are derived by:

- Addressing the significance of the failure through application of PRA/HRA importance measures.
- Classifying the causes and circumstances surrounding the failure or degraded human performance.
- Illuminating the characteristics of the failure (for example, being task specific or due to overall plant culture).
- Determining whether the failure is isolated or has generic or common cause implications.

[START COM 18.13-001] The HPM program will be implemented prior to the beginning of the first licensed operator training class. **[END COM 18.13-001]**

18.13.4 Results of Human Performance Monitoring

The results of the HPM activity are summarized in a RSR. The content of the HPM RSR is described in Reference 18.13-2.

18.13.5 COL Information

18.13-1-A Milestone for HPM Implementation

The COL item is addressed in Section 18.13.3.

18.13.6 References

18.13-1 *GE Hitachi Nuclear Energy, "ESBWR Man-Machine Interface System and Human Factors Engineering Implementation Plan," NEDE-33217P, Class III (Proprietary), Revision 6, February 2010, and NEDO-33217, Class I (Non-proprietary), Revision 6, February 2010.*

18.13-2 *GE Hitachi Nuclear Energy, "ESBWR Human Factors Engineering Human Performance Monitoring Implementation Plan," NEDO-33277, Class I (Non-proprietary), Revision 4, January 2010.*

18.13-3 American National Standards Institute, "Nuclear Power Plants Simulators for Use in Operator Training and Examination," ANSI/ANS 3.5-1998, April 1998.