GE-Hitachi Nuclear Energy

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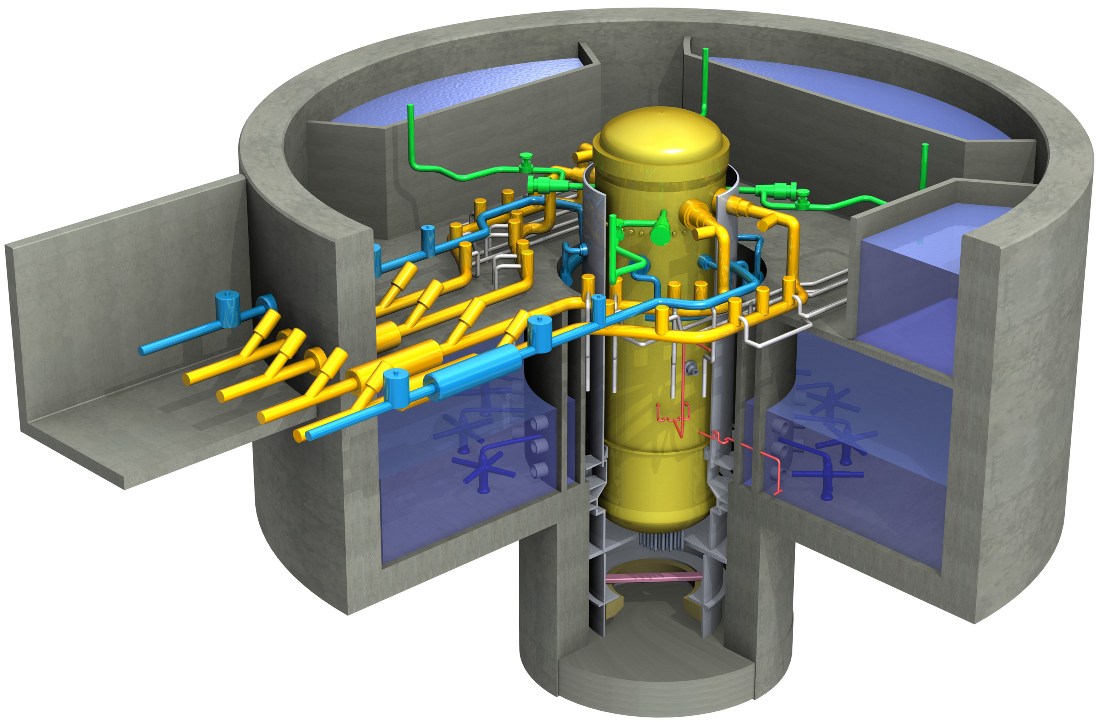

ESBWR Design Control Document
Tier 2

Chapter 18
Human Factors Engineering

Contents

List of Tables

List of Illustrations

Global Abbreviations And Acronyms List

Term	**Definition**
10 CFR	Title 10, Code of Federal Regulations
ABWR	Advanced Boiling Water Reactor
ADS	Automatic Depressurization System
ANS	American Nuclear Society
ANSI	American National Standards Institute
AOF	Allocation of Functions
AOP	Abnormal Operating Procedures
APRM	Average Power Range Monitor
ARI	Alternate Rod Insertion
ARP	Annunciator Response Procedures
ATWS	Anticipated Transients Without Scram
BRR	Baseline Record Review
BTU	British Thermal Unit
BWR	Boiling Water Reactor
BWROG	Boiling Water Reactor Owners Group
CBP	Containment Bypass and Leakage
CFR	Code of Federal Regulations
CIS	Containment Inerting System
COL	Combined Operating License
CRD	Control Rod Drive
D3	Defense-in-Depth and Diversity
DAC	Design Acceptance Criteria
DCD	Design Control Document
DCIS	Distributed Control and Information System
DPV	Depressurization Valve
DW	Drywell
EAL	Emergency Action Level
ECCS	Emergency Core Cooling System
EOF	Emergency Operations Facility
EOP	Emergency Operating Procedures
EPG	Emergency Procedure Guidelines
FAPCS	Fuel and Auxiliary Pools Cooling System
FMCRD	Fine Motion Control Rod Drive
FRA	Functional Requirements Analysis
GDC	General Design Criteria
GDCS	Gravity-Driven Cooling System
GE	General Electric Company
GEH	GE-Hitachi Energy Nuclear

Global Abbreviations And Acronyms List

Term	Definition
GEEN	GE Energy Nuclear
GENE	GE Nuclear Energy
GPP	General Plant Procedures
GTG	General Training Guidelines
HA	Human Actions
HFE	Human Factors Engineering
HFEITS	Human Factors Engineering Issues Tracking System
HPM	Human Performance Monitoring
HRA	Human Reliability Assessment
HSI	Human-System Interface
HVAC	Heating, Ventilation and Air Conditioning
IC	Ion Chamber
IC	Isolation Condenser
I&C	Instrumentation & Control
IOP	Integrated Operating Procedure
LCS	Local Control Station
LCO	Limiting Conditions for Operation
LHGR	Linear Heat Generation Rate
LOCA	Loss-of-Coolant-Accident
LPCI	Low Pressure Coolant Injection
MCC	Motor Control Center
MCR	Main Control Room
MMIS	Man-Machine Interface Systems
MSIV	Main Steam Isolation Valve
MSL	Main Steam Line
MUX	Mutliplexer
N-DCIS	Nonsafety-Related Distributed Control and Information System
NPSH	Net Positive Suction Head
NRC	Nuclear Regulatory Commission
OER	Operating Experience Review
P&ID	Piping and Instrumentation Diagram
PCCS	Passive Containment Cooling System
PCT	Peak Cladding Temperature
PRA	Probabilistic Risk Assessment
Q-DCIS	Safety-Related Distributed Control and Instrumentation System
QA	Quality Assurance
RB	Reactor Building
RBHV	Reactor Building HVAC (Heating, Ventilation and Air Conditioning)
RC&IS	Rod Control and Information System

Global Abbreviations And Acronyms List

Term	Definition
RHR	Residual Heat Removal (function)
RPS	Reactor Protection System
RPV	Reactor Pressure Vessel
RSS	Remote Shutdown System
RSR	Results Summary Report
RWM	Rod Worth Minimizer
SAG	Severe Accident Guidelines
SBWR	Simplified Boiling Water Reactor
SDC	Shutdown Cooling
SFGA	System Functional Gap Analysis
SLC	Standby Liquid Control
SOP	System Integrated Procedures
SP	Setpoint
SRO	Senior Reactor Operator
SRV	Safety Relief Valve
SRVDL	Safety Relief Valve Discharge Line
SSC(s)	Structure, System and Component(s)
SSLC	Safety System Logic and Control
S&Q	Staffing and Qualification
TA	Task Analysis
TAF	Top of Active Fuel
TMI	Three Mile Island
TSC	Technical Support Center
V&V	Verification and Validation
VDU	Video Display Unit or Visual Display Unit
WW	Wetwell

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. Because technology is continually advancing, details of the HFE design need not be complete before the NRC issuance of a design certification. The HFE focus is on the design process.

This chapter describes the ESBWR Human-System Interface (HSI) design goals and bases, the HSI design features, the detailed HSI design, and 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 detail in Licensing Topical Report, titled "*Man Machine Interface System and Human Factors Engineering Implementation Plan*" (Reference 18.1-1). 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 with off-site dose limits) are documented in item 7 of DCD Tier 1 Table 3.3-1 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 Assessment (HRA) confirm that the Emergency Procedure Guidelines (EPGs) and severe accident guidance effectively address:

- Preventing core damage,
- Recovering from core damage,
- Maintaining containment integrity, and
- 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 that:

- 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; and
- 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; and

(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.

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; and

(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.

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 and detailed in Reference18.1-1.

- Operating Experience Review (OER);
- Functional Requirements Analysis (FRA);
- Allocation of Functions (AOF);
- Task Analysis (TA);
- Staffing and Qualifications (S&Q);
- Human Reliability Analysis;
- Human System Interface;
- Procedure Development;
- Training Development;
- Human Factors Verification and Validation (V&V);
- Design Implementation; and
- 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. Important aspects of defense-in-depth are identified in RG 1.174, and include:

- 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 (10 CFR) Part 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. It is also possible to add a safety margin (if desired) to HAs by demonstrating that 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 operation capabilities;
- HSI design uses only proven technology;
- The reference ABWR plant is the Lungmen project (Taiwan Power). Other ABWR plants in Japan include, Kashiwazaki-Kariwa 6 & 7 (TEPCO), Hamaoka 5 (Chubu Electric), and 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 cooldown the reactor 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; and
- The design basis for the RSS is specified in Subsection 7.4.2.

As part of Section 18.2 and in detail in Reference 18.1-1, detailed design criteria are specified. 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 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 described in Section 18.2 and Reference 18.1-1, 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 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 described in license topical reports. Reference 18.1-1, the MMIS and HFE Implementation Plan, presents 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:

(1) Definition of the standard design features of the control room HSI, and

(2) Definition of the inventory of controls and instrumentation. These are necessary for the operators to follow the ESBWR EPGs and to complete the important operator actions described in the PRA.

18.1.2.1 *Standard Design Features*

The ESBWR control room HSI design contains 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:

- 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; and
- 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 based upon the operation strategies. This analysis defines a minimum set of controls, displays, and alarms that allow the operators to perform the actions specified in the EOPs and the important operator actions identified in the PRA.

18.1.2.3 *Detailed Design Implementation Process*

The process by which the detailed equipment design implementation of the ESBWR HSI is completed 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 RSS design is described in Subsection 7.4.2. Parameters that are displayed and/or controlled from Division I and Division II in the MCR are also displayed and/or 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 Subsection 7.3.4.

Divisional separation for control, alarm, and display equipment is maintained. The SSLC processors provide alarm signals to their respective safety-related alarm processors and provide display information to the divisionally dedicated VDUs. The SSLC microprocessors communicate with their 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 if control of a system component is required.

Divisional isolation devices are provided between the safety-related systems and nonsafety-related communication networks so that failures in the nonsafety-related equipment have no affect on the ability of the 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 Section 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 is 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, availability of safety systems with mimic on the main control room during plant normal, abnormal, and emergency operating conditions is indicated.

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. 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 Energy, "ESBWR Man-Machine Interface System and Human Factors Engineering Implementation Plan," NEDE-33217P, Class III (Proprietary), Revision 3, March 2007, and NEDO-33217, Class I (non-proprietary), Revision 3, March 2007.

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

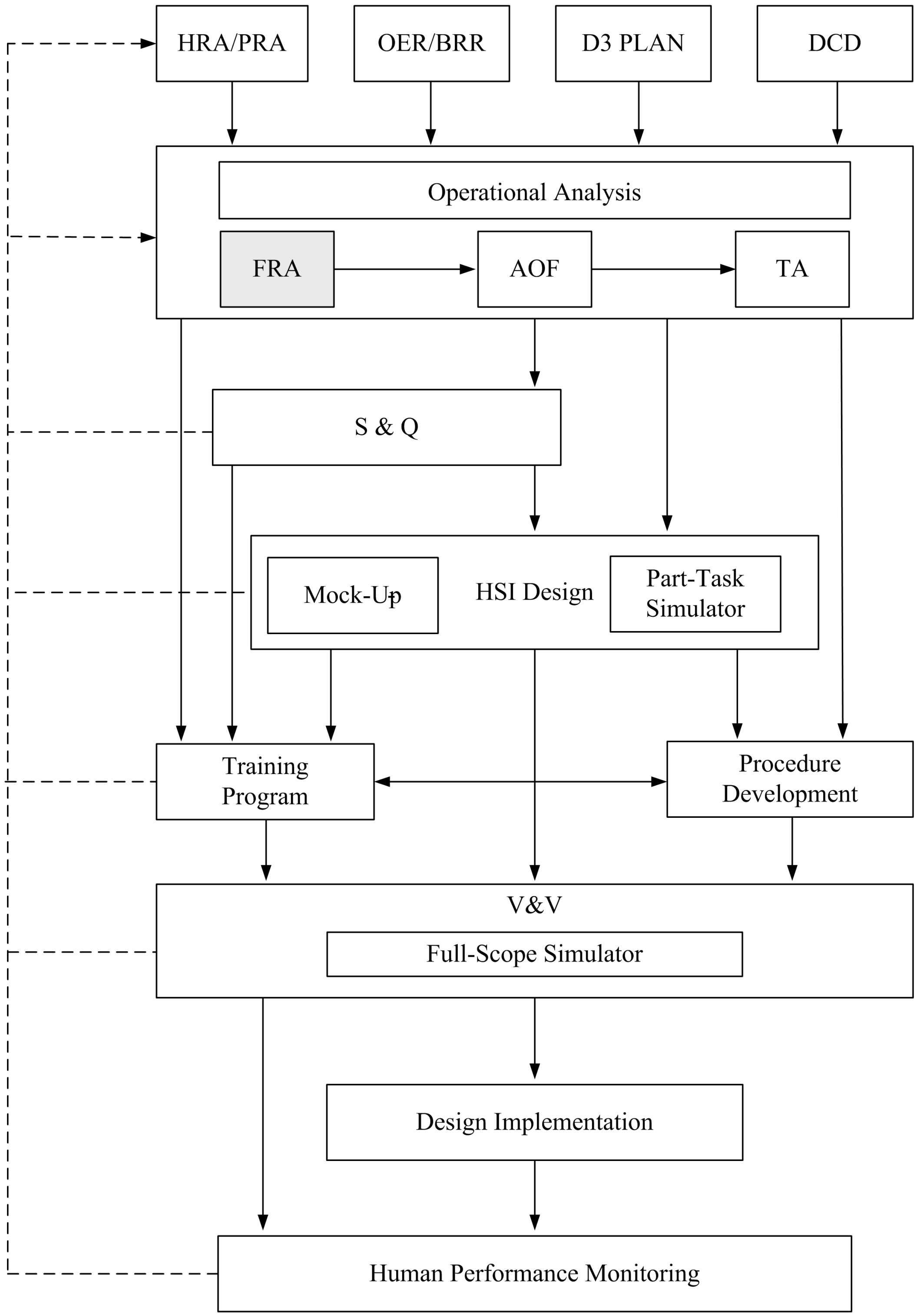

Figure 18.1-1. HFE Implementation Process

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 MMIS 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 LCS (those with a safety-related function or as identified by high level task analysis) areas of operational interface.

The MMIS and HFE Implementation Plan identifies the qualifications and experience of individuals who comprise the HFE design team and establishes the processes through which the HFE design team performs its functions. Included in the MMIS and HFE Implementation Plan is a system for documenting human factors issues that may be identified throughout the implementation of the designs, 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 Program Development;
- Human Factors Verification and Validation;
- Design Implementation; and
- Human Performance Monitoring.

The Implementation Plans establish methods and criteria for the conduct of each of these HFE-related activities, which are consistent with accepted HFE practices and principles. (For additional detailed information regarding the scope and content of the HFE Program and Implementation Plans, refer to Reference 18.2-1.

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 HSI, 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; and

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 is responsible 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; and

viii. HSI design configuration control procedures.

(2) The HFE 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; and

f. HSI equipment technologies that are alternatively selected for application in the MCR, RSS, TSC, EOF and LCSs design implementations ensure that:

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; and

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, including:

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 (e.g., review forms, 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; and

vii. Definitions of the procedures that will govern the internal management of the HFE design team.

d. Definition of the HFE 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; and
- 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; and
- 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 defined in Reference 18.2-1.

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; and

iv. Description of the HFE Program requirements that are communicated to applicable personnel and organizations. Personnel and organizations include those which 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 HFE 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; and

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 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 (e.g., 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 Energy, "ESBWR Man-Machine Interface System and Human Factors Engineering Implementation Plan," NEDE-33217P, Class III (Proprietary), Revision

3, March 2007, and NEDO-33217, Class I (non-proprietary), Revision 3, March 2007.

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. The plan for the ESBWR OER is described in the Reference 18.3-2. An overview of the OER topics is summarized in the subsections below.

18.3.1 Objectives and Scope of OER

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 HAs;
- Specifically-identified industry issues; and
- 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; and
  - 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; and
  - 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 a 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; and
- 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 *HFE 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. For example, if a computer operated support system, computerized procedures, or advanced automation are planned, HFE issues associated with such use is 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;
- TMI issues;
- NRC generic letters and information notices;
- Reports of the former NRC Office for Analysis and Evaluation of Operational Data;
- Low power and shutdown operations; and
- Operating experience reviews (OERs).

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), break in MUX line);
  - HSI equipment and processing failure (for example, loss of video display units, loss of data processing, 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 (CR) power supplies, and safety/relief valve transients);
  - Accidents (for example, main steam line break, positive reactivity addition, control rod insertion at power, Anticipated Transients Without Scram (ATWS), and various-sized loss-of-coolant accidents); and
  - 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; and
  - 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 OER Results

The results of the OER are summarized in the OER Results Summary Report (RSR). The RSR provides the OER process description along with the analyses that were used. These include:

- List of risk important HAs from the predecessor plant and their resolutions;
- List of risk important HAs from the OER requiring special attention in the design process;
- Personnel interviews conducted at predecessor plants with summarized results;

- Sources of OER information; and
- Summaries of OER issues and improvements.

The OER results summary report is included as ITAAC item 1 of Table 3.3-1 in DCD Tier 1. Reference 18.3-2 provides additional details of the OER Plan.

18.3.4 COL Information

None

18.3.5 References

18.3-1 GE Energy, "ESBWR Man-Machine Interface System and Human Factors Engineering Implementation Plan," NEDE-33217P, Class III (Proprietary), Revision 3, March 2007, and NEDO-33217, Class I (non-proprietary), Revision 3, March 2007.

18.3-2 GE Energy, "ESBWR Operating Experience Review (Human Factors) Implementation Plan," NEDO-33262, Class I (non-proprietary), Revision 1, January 2007.

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

(1) The FRA Implementation Plan, Reference 18.4-2, establishes:

a. Methods for conducting the FRA consistent with accepted HFE practices and principles;

b. Strategies to define the system functions required that determine HSI requirements;

c. The process to identify critical safety functions (for example, those functions required to control radionuclide release); and

d. Function descriptions in terms of inputs, functional processes, functional operations, outputs, feedback, and interface requirements.

(2) The FRA Implementation Plan includes:

a. Methods to identify system and sub-system level functions based on the ESBWR mission and goals;

b. Logical function sequence arrangements that can be traced from ESBWR plant level goals to specific tasks;

c. Methods to develop function graphical descriptions starting at a "top level" and continuing to lower levels until a specific action emerges;

d. The method to develop detailed function descriptions, which encompasses:

i. Identification of observable parameters that indicate system status;

ii. Control of processes and data required to accomplish the function, and

iii. Determination of the manner in which functions are to be properly discharged.

e. Analysis methods that define the integration of closely related sub-functions so that they are treated as a unit; and

f. Analysis methods that divide identified sub-functions into two groups according to whether:

i. Common achievement of the sub-function is an essential condition for the accomplishment of higher-level function; and

ii. The sub-function is an alternative supporting function to a higher-level function or the sub-function accomplishment is not necessarily pre-required for a higher-level function.

(3) The results of the FRA are summarized in the FRA RSR. The RSR provides the plant functional requirements, along with an outline of the analysis that was used. Reports are generated following each phase of the analysis, that is, high-level Plant FRA, Design FRA,

Detailed FRA and Economic FRA. A report will also summarize the results of the System Functional Gap Analysis (SFGA). The FRA RSR may be combined with the RSR(s) from AOF and TA.

Other RSR outputs include:

- Initial inventory of plant parameters, indications, and controls;
- Emergency Procedure Guidelines outlines;
- HSI design inputs and recommendations;
- Initial inventory of simulator scenarios for V&V;
- Emergency Action Level (EAL) procedure outlines;
- Staffing requirements and recommendations;
- Outlines and inputs to System and Integrated Operating Procedures (SOPs/IOPs);
- Outlines and inputs to Annunciator Response Procedures (ARPs);
- Outlines and inputs to General Plant Procedures (GPP);
- Outlines and inputs to Abnormal Operating Procedures (AOPs); and
- Outlines and inputs to Calibration, Inspection, and Testing Procedures.

The FRA results summary report is included as ITAAC item 2 of Table 3.3-1 in DCD Tier 1.

18.4.2 Allocation of Function Implementation Plan

(1) The AOF Implementation Plan, Reference 18.4-3, establishes:

a. Methods and criteria for the execution of function allocation consistent with accepted HFE practices and principles;

b. System and function definitions generating human performance requirements based on the expected user population;

c. Documentation of the allocation of functions to personnel, system elements, and personnel system combinations reflects:

   i. Areas of human strengths and limitations;

   ii. Sensitivity, precision, time, and safety requirements;

   iii. Reliability of system performance; and

   iv. Necessary personnel (numbers and skills) required for operating and maintaining the SSC.

d. Documentation of the allocation criteria, rationale, analyses, and procedures; and

e. Analyses confirming that personnel can perform tasks allocated to them while maintaining operator situational awareness, workload and vigilance.

(2) The AOF Implementation Plan includes:

a. Establishment of a structured basis and criteria for function allocation; and

b. Definition of function allocation analyses requirements, including:

   i. Objectives and requirements;

   ii. Alternative function allocations;

   iii. Selection criteria;

   iv. Evaluation criteria;

   v. Test and analysis methods, and

   vi. Assessment methods.

(3) The results of the Function Allocation are summarized in the AOF RSR. The RSR provides the plant function allocations, along with an outline of the analyses that were used. A separate report is generated following each phase of the analysis, that is, high-level Plant FRA, Design FRA, Detailed FRA and Economic FRA. The AOF RSR may be combined with the RSR(s) from FRA and TA.

Other RSR outputs include:

- Initial inventory of plant parameters and controls;
- EPG outlines;
- HSI design inputs and recommendations;
- Initial inventory of simulator scenarios for V&V;
- EAL procedure outlines;
- Staffing requirements and recommendations;
- Outlines and inputs to SOPs and IOPs;
- Outlines and inputs to ARPs;
- Outlines and inputs to GPPs;
- Outlines and inputs to AOPs; and
- Outlines and inputs to calibration, inspection, and testing procedures.

The AOF results summary report is included as ITAAC item 2 of Table 3.3-1 in DCD Tier 1.

18.4.3 COL Information

None

18.4.4 References

18.4-1 GE Energy, "ESBWR Man-Machine Interface System and Human Factors Engineering Implementation Plan," NEDE-33217P, Class III (Proprietary), Revision 3, March 2007, and NEDO-33217, Class I (non-proprietary), Revision 3, March 2007.

18.4-2 GE Energy, "ESBWR Functional Requirements Analysis Implementation Plan," NEDO-33219, Class I (non-proprietary), Revision 1, January 2007.

18.4-3 GE Energy, "ESBWR Allocation of Functions Implementation Plan," NEDO-33220, Class I (non-proprietary), Revision 1, March 2007.

18.5 TASK ANALYSIS

The task analysis activity is conducted in accordance with the project guidelines described in reference 18.5-1.

18.5.1 Task Analysis Implementation Plan

(1) The TA Implementation Plan, Reference 18.5-2, establishes:

a. Methods for conduct of the TA consistent with accepted HFE practices and principles;

b. Scope of the TA including actions performed at the MCR, RSS, TSC, EOF, and at the applicable LCS HSI;

c. Range of plant operating conditions, including: startup, normal and abnormal operations, transients, refueling, low power, and shutdown conditions;

d. HSI operations during periods of maintenance, testing, and inspection of ESBWR SSCs;

e. Links between task descriptions and risk importance, function achievement, human error potential, and effect of task failure;

f. Descriptions of the personnel activities required for successful completion of tasks; and

g. Requirements for alarms, displays, data processing, and controls.

(2) The TA Implementation Plan includes:

a. Methods and data sources used in the conduct of the task analysis;

b. Methods for conducting the initial (high level) task analysis:

i. Converting functions to tasks;

ii. Developing narrative task descriptions;

iii. Developing the basic statement of the task functions; and

iv. Decomposition of tasks to individual activities,

c. The methods for developing detailed task descriptions that address:

i. Information requirements;

ii. Decision-making requirements;

iii. Response requirements;

iv. Feedback requirements;

v. Personnel workload;

vi. Task support requirements;

vii. Workplace factors;

viii. Staffing and communication requirements, and

ix. Task hazards.

d. Methods to identify critical tasks during postulated event scenarios of a common mode failure; including, for example operator actions to:

   i. Isolate the reactor; and

   ii. Inject water into the reactor.

e. Methods for establishing data and control requirements;

f. Methods for analyzing alarm, display, processing, and control requirements;

g. Methods through which the application of task analysis results are assembled and documented to provide input to the development of personnel training programs; and

h. Methods used to evaluate the TA results.

(3) The results of the TA are summarized in the TA RSR. The RSR provides the tasks, along with an outline of the analyses that were used. A separate report is generated following each phase of the analysis, that is, high-level Plant FRA, Design FRA, Detailed FRA and Economic FRA. The TA RSR may be combined with the RSR(s) from FRA and AOF.

Other RSR outputs include:

- Initial inventory of plant parameters and controls;
- EPG outlines;
- HSI design inputs and recommendations;
- Initial inventory of simulator scenarios for V&V;
- EAL guidance;
- Staffing requirements and recommendations;
- Outlines and inputs to SOPs and IOPs;
- Outlines and inputs to ARPs;
- Outlines and inputs to GPPs;
- Outlines and inputs to AOPs; and
- Outlines and inputs to calibration, inspection, and testing procedures.

The TA results summary report is included as ITAAC item 3 of Table 3.3-1 in DCD Tier 1.

18.5.2 COL Information

None

18.5.3 References

18.5-1 GE Energy, "ESBWR Man-Machine Interface System and Human Factors Engineering Implementation Plan," NEDE-33217P, Class III (Proprietary), Revision 3, March 2007, and NEDO-33217, Class I (non-proprietary), Revision 3, March 2007.

18.5-2 GE Energy, "ESBWR Task Analysis Implementation Plan," NEDO-33221, Class I (non-proprietary), Revision 1, March 2007.

18.6 STAFFING AND QUALIFICATIONS

18.6.1 Background

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

18.6.2 Objectives and Scope of Staffing and Qualification Analyses

The objectives of the staffing and qualifications analyses and the scope of the analyses performed are provided. The scope includes the number and qualification of personnel for the full range of plant conditions and tasks including operational tasks (normal, abnormal, and emergency), plant maintenance and testing, including surveillance testing. The personnel considered in the scope are licensed control room operators as defined in 10 CFR 50.54 and the categories of personnel defined by 10 CFR 50.120 including 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, any other plant personnel who perform tasks that are directly related to plant safety are also addressed.

18.6.3 ESBWR Baseline Staffing Assumptions

The preliminary staffing assumption for a ESBWR unit is depicted in Table 18.6-1 and consists of the onsite staffing by operators and senior operators licensed under 10 CFR part 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 process in accordance with Figure 18.1-1 and Reference 18.6-1. The basis for staffing and qualifications plan addresses the following issues.

18.6.4.1 *Operating Experience Review*

Operating experience review addresses the following issues:

- Operational problems and strengths that resulted from staffing levels in ABWR reference systems;
- Initial staffing goals and their bases including staffing levels of ABWR reference plants;
- Systems and a description of significant similarities and differences between ABWR reference systems and ESBWR systems;

- Staffing considerations described in NRC Information Notice 95-48, "Results of Shift Staffing Study"; and
- 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 addresses the following issues:

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

18.6.4.3 *Task Analysis*

Task analysis addresses the following issues:

- 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; and
- Staffing considerations described by the application of ANSI/ANS 58.8-1994, "Time Response Design Criteria for Safety-Related Operator Actions."

18.6.4.4 *Human Reliability Analysis*

HRA addresses the following issues:

- Effect of overall staffing levels on plant safety and reliability;
- Effect of overall staffing levels and crew coordination for risk-important HAs; and
- 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 addresses the following issues:

- 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; and
- The availability of plant information from individual workstations and group-view interfaces.

18.6.4.6 *Procedure Development*

Procedure development addresses the following issues:

- Staffing demands resulting from requirements for concurrent use of multiple procedures; and
- 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 Qualification Analyses

The Staffing and Qualification (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 18.6-1.

18.6.6 Results of Staffing and Qualifications Analyses

The results of the S&Q analysis are summarized in the RSR. The RSR discusses in greater detail the methodology employed and provides results of the staffing analyses. The RSR includes enough detail to show the methodology implemented providing the results and the final staffing levels for all personnel identified in the above scope. This is in conjunction with compliance with all regulatory requirements as delineated in 10 CFR 50.54.

Other RSR S&Q Outputs include:

a. Demonstrated compliance with 10 CFR 50.54;
b. Staffing analysis results in detail;
c. Final staffing levels, including the number of personnel with a specific qualification and requirements for achieving the qualification;
d. Staffing and qualification team members and backgrounds; and

e. Bases for S&Q ensuring that issues and concerns raised in other HFE activities are addressed.

The S&Q results summary report is included as ITAAC item 4 of Table 3.3-1 in DCD Tier 1.

18.6.7 COL Information

None

18.6.8 References

18.6-1 GE Energy, "ESBWR Man-Machine Interface System and Human Factors Engineering Implementation Plan," NEDE-33217P, Class III (Proprietary), Revision 3, March 2007, and NEDO-33217, Class I (non-proprietary), Revision 3, March 2007.

18.6-2 GE Energy, "ESBWR HFE Staffing and Qualifications Implementation Plan," NEDO-33266, Class I (non-proprietary), Revision 1, March 2007.

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

Table 18.6-1

ESBWR Staffing Assumptions

Quantity	Qualification	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

[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

HRA is performed in accordance with the project guidance described in Reference 18.7-1 and as a part of a PRA for both pre- and post-initiator human actions. The HRA activity is conducted in accordance with the HRA Implementation Plan, Reference 18.7-2.

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 is provided in Chapter 19 to support NRC certification information requirements. The performance of the HRA quantification is addressed in Chapter 19. The impact of the risk important human actions and human-error mechanisms on the HSI design is addressed in the Chapter 18.

The scope for using HRA in HFE activities includes:

(1) An assessment of the potential for and mechanisms of human error that may affect plant safety, particularly the risk important HAs;

(2) An evaluation of potential human errors in the design of HFE aspects of the plant to address the likelihood of personnel error, to detect errors and recover from them;

(3) Human errors identified and quantified in the PRA are further evaluated to determine if new or modified HSI design features are needed to reduce the likelihood and impact of errors; and

(4) The HRA activity quantitatively integrates the HFE program into the PRA and the PRA insights into the HFE program.

18.7.2 Methodology of Human Reliability Analysis

The initial PRA/HRA results and the risk-important HAs are provided to the HFE team to ensure that important HAs are 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 leading to an as built PRA. The results of the PRA/HRA are used by the HFE design team (through HSI design, procedural development, and training) to minimize the likelihood of operator error and provide for error detection and recovery capability. The use of passive cooling systems, increased automation and computer-based HSIs simplifies the way that operators interact with the ESBWR compared with previous BWRs. For example, passive cooling eliminates the need for operating and controlling forced cooling systems. The operators concentrate more on monitoring and determining a course of action.

The PRA/HRA is used to identify the risk-important human actions for evaluation in the HFE process. The process for determining the risk-important HAs 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; and
- The low power and shutdown PRA.

The importance of each HA is determined by using various importance measures (e.g., Fussell-Vesely, achievement worth, or risk reduction worth), HRA sensitivity analyses, and relative threshold criteria based on the ESBWR systems failure probability, the core damage frequency, the large early release frequency and the conditional core damage frequency for selecting the PRA accident scenarios (or cutsets) considered for developing and maintaining a list of risk-important actions.

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 important actions can be performed using the MMIS for the risk important human actions. The methods include discussions and walk through analyses with personnel having operational experience and the use of a plant-specific control room part task or full scope simulator.

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 the Emergency Core Cooling system (ECCS) to operate properly.

The HRA modeling for the PRA benefits from the HFE operational analysis that defines operator functions and task requirements from an analysis of plant and system functions.

The HRA model updates consider 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 are summarized in the RSR. The RSR provides the list of risk important HAs and summarizes how the risk-important HAs and their associated tasks and scenarios are addressed during the various phases of the design process (for example, in allocation of functions analyses, task analyses, HSI design, procedure development, and training). The HFE process ensures that the tasks identified are well supported by HSI design features and are within acceptable human performance capabilities. The RSR also discusses validation of the HRA assumptions.

The HRA results summary report is included as ITAAC item 5 of Table 3.3-1 in DCD Tier 1.

18.7.4 COL Information

None

18.7.5 References

18.7-1 GE Energy, "ESBWR Man-Machine Interface System and Human Factors Engineering Implementation Plan," NEDE-33217P, Class III (Proprietary), Revision 3, March 2007, and NEDO-33217, Class I (non-proprietary), Revision 3, March 2007.

18.7-2 GE Energy, "ESBWR HFE Human Reliability Analysis Implementation Plan," NEDO-33267, Class I (non-proprietary), Revision 2, March 2007.

18.8 HUMAN-SYSTEM INTERFACE DESIGN

References 18.8-1 and 18.8-2 describe the process by which areas of operator interfaces are established and evaluated. The primary areas of human interface are the ESBWR MCR, RSS, TSC, EOF, and LCSs with safety-related functions or identified through high-level task analysis. These results of HSI efforts are summarized in the HSI results summary report and are available for the conformance reviews. Satisfaction of the specific requirements described in Reference 18.8-1 results in full compliance with the Certified Design Commitment and the corresponding requirements presented in the Tier 1 (Rulemaking) Design Acceptance Criteria (DAC).

18.8.1 HSI Design Implementation Plan

(1) The HSI Design Implementation Plan, Reference 18.8-2, establishes:

a. Methods and criteria for HSI equipment design and evaluation of HSI human performance, equipment design, and associated work place factors, (for example, 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;

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

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

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

ii. 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.

(2) The HSI Design Implementation Plan includes:

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. Verification that the design features, the HSI equipment technologies, and the displays, controls, and alarms are incorporated as requirements on the HSI design; and

e. 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 results of the HSI Design Implementation are summarized in the RSR including:

a. The style guide developed for the detailed design.

i. The development and basis for the guide,

ii. The scope, topical contents and procedures; and

iii. Procedures used to maintain a style guide.

b. Final HSI design.

i. Overview of HSI design and key features.

ii. Safety aspects of the HSI.

The HSI results summary report is included as ITAAC item 6 of Table 3.3-1 in DCD Tier 1.

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

i. HSIs are modified and updated;

ii. Temporary HSI changes are made;

iii. Operator defined HSIs are created (as temporary displays defined by operators for monitoring specific plant situations); and

iv. The procedures governing permissible operator initiated changes to HSIs are described.

18.8.2 COL Information

None

18.8.3 References

18.8-1 GE Energy, "ESBWR Man-Machine Interface System and Human Factors Engineering Implementation Plan," NEDE-33217P, Class III (Proprietary), Revision 3, March 2007, and NEDO-33217, Class I (non-proprietary), Revision 3, March 2007.

18.8-2 GE Energy, "ESBWR Human-System Interface Design Implementation Plan," NEDO-33268, Class I (non-proprietary), Revision 2, March 2007.

18.9 PROCEDURE DEVELOPMENT

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

The HFE team generates the implementation plan for procedure development, Reference 18.9-2, using applicable requirements from NUREG-0800 section 13.5. The reference ESBWR normal operating (SOP/IOP), abnormal operating, alarm response, test, and EOPs 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 that are 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 that 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; and
- 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 that the integrated plan procedures are consistent with accepted HFE practices and principles. The scope of the procedures addressed in this section is:

- EOPs including Generic Technical Guidelines (GTGs) for EOPs;
- Plant and system operations (including startup, power, and shutdown operations);
- Test and maintenance;
- Abnormal and emergency operations; and
- 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 18.9-1 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; and
- GTGs 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 that 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:

- *Writers Guide*. How the writer's guide ensures that 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 GTGs and EOPs, for example, symptom-based procedures with clearly specified entry conditions.
- *Procedures V&V*. The procedure V&V program including the use of simulation.
- *Computer-based Procedures*. The development, V&V, and implementation process of computer-based procedures (CBPs) includes a description of the HSI for the CBPs. An analysis of the available alternatives in the event of loss of CBPs 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 are summarized in the RSR. The RSR provides the list of the final set of procedures and procedure support equipment developed using the above methodology. The RSR includes sufficient detail to see how the methodology was implemented to provide the results.

Other RSR Procedure Development outputs include:

- Process for procedure maintenance and control of updates (Subsection 18.9.2);
- Operator access and use of procedures for both hard copy and computer-based procedures (Subsection 18.9.2); and
- Procedure, storage and laydown area for use of hardcopies in the MCR, RSS, TSC, EOF, and LCSs (with a safety-related function or as defined by high level TA).

The procedure development results summary report is included as ITAAC item 7 of Table 3.3-1 in DCD Tier 1.

18.9.4 COL Information

None

18.9.5 References

18.9-1 GE Energy, "ESBWR Man-Machine Interface System and Human Factors Engineering Implementation Plan," NEDE-33217P, Class III (Proprietary), Revision 3, March 2007, and NEDO-33217, Class I (non-proprietary), Revision 3, March 2007.

18.9-2 GE Energy, "ESBWR HFE Procedure Development Implementation Plan," NEDO-33274, Class I (non-proprietary), Revision 2, March 2007.

18.10 TRAINING PROGRAM DEVELOPMENT

Training of plant personnel is an important factor in ensuring safe and reliable operation of nuclear power plants. The training program provides reasonable assurance that plant personnel have the knowledge, skills, and abilities to properly perform their roles and responsibilities. Training program development is conducted in accordance with the project guidance described in reference 18.10-1 and implementation activities described in Reference 18.10-2.

18.10.1 Purpose

The aim of an 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, or training;
- 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; and
- 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 include the following:

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

18.10.3 Methodology of Training Program Development

The activities under 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, 52.78, and 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, GTG) 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 reference training simulator and part-task training simulators needed to satisfy training design requirements and the guidance contained in ANSI 3.5 and Regulatory Guide 1.149 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; and
- 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 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, upset, and emergency);
- Specific operational activities (for example, operations, calibrations, inspections, and testing); and
- 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); and
- A full range of relevant HSIs (for example, MCR, RSS, TSC, EOF, LCSs), (for example, display space navigation, operation of "soft" controls) as is appropriate for each job classification.

18.10.4.2 *Organization of Training*

The specific roles for development of training requirements, development of training information sources, development of training materials, and implementation of the training program are defined in a training plan. 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.

The HFE team defines the facilities and resources to be used during different phases of the design and operation. The facilities include full-scope simulator and part-task training simulators. The plan for these facilities follows the guidance contained in ANSI 3.5 and Regulatory Guide 1.149.

18.10.4.3 *Learning Objectives*

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

- Licensing Basis - 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 are provided by the HFE team;
- 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 human activities 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; and
- 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; and
- 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 Plan are summarized in the RSR.

RSR Training Program Development outputs include:

- The Training Program Design;
- The methods used for evaluating the overall effectiveness of the training programs;
- Process used to ensure trainee mastery of training objectives, as well as overall proficiency including:
  - Written and oral tests,
  - Performance during walk throughs,
  - Simulator,
  - On-the-job evaluation, and
  - Descriptions of the evaluation criteria.
- Methods for verifying the accuracy and completeness of training materials;
- Methods for refining and updating the content and conduct of training; and
- Planned remediation program.

The training development results summary report is included as ITAAC item 8 of Table 3.3-1 in DCD Tier 1.

18.10.6 COL Information

None

18.10.7 References

18.10-1 GE Energy, "ESBWR Man-Machine Interface System and Human Factors Engineering Implementation Plan," NEDE-33217P, Class III (Proprietary), Revision 3, March 2007, and NEDO-33217, Class I (non-proprietary), Revision 3, March 2007.

18.10-2 GE Energy, "ESBWR Training Development Implementation Plan," NEDO-33275, Class I (non-proprietary), Revision 1, February 2007.

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 CR 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)

18.11 HUMAN FACTORS VERIFICATION AND VALIDATION

This section describes the following:

- The five main activities of HFE V&V:
  - (1) Operational Conditions Sampling (per NUREG 0711r2);
  - (2) Design Verification;
    - a. Inventory and Characterization;
    - b. HSI Task Support Verification; and
    - c. HFE Design Verification;
  - (3) Integrated System Validation;
  - (4) Human Factors Issue Resolution Verification; and
  - (5) Final Plant HFE/HSI Design Verification.
- Relationship between HFE V&V and hardware/software V&V;
- HFE V&V team;
- End-users as participants and test subjects; and
- Documentation, reporting, performance measurement, and integration of results.

Figure 18.1-1 provides an overview of the integrated HFE V&V activities with their associated inputs and outputs.

18.11.1 Human Factors Verification and Validation Implementation

The ESBWR MMIS and HFE Implementation Plan, Reference 18.11-1, establishes:

(1) Human factors V&V methods and criteria consistent with accepted HFE practices and principles;

(2) The scope of the evaluations of the integrated HSI including:

a. HSI, addressing both 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 normal and emergency operating procedures; and

c. HSI work environment.

(3) The process for static and/or "part-task" mode evaluations of the HSI equipment to confirm that the controls, displays, and data processing functions identified in the task analyses are designed per accepted HFE guidelines and principles;

(4) The integrated system validation of HSI equipment with each other, with the operating personnel, and with the plant normal and emergency operating procedures through the conduct of dynamic task performance testing. The dynamic task performance testing and evaluations are performed over the full scope of the integrated HSI design using dynamic HSI prototypes (that is, prototypical HSI equipment which is dynamically-driven using real

time plant simulation computer models). When a new HSI design is compared to a previous HSI design differences can be identified. Existing test and evaluation results can be compared to new analysis results. A limited scope dynamic task performance is adequate to satisfy the V&V requirements. The methods for defining the scope and application of the dynamic HSI prototype, past test results and other evaluation tools are documented in the ESBWR HFE V&V implementation plan;

(5) The process by which Human Factors issues are identified and tracked; and

(6) Final plant HFE/HSI Design Verification performed and documented as a basis to human performance monitoring.

18.11.2 Results of HFE V&V

The results of the HFE V&V activities are summarized in the RSR including Human Engineering Discrepancy (HED) identification and resolutions.

The HFE V&V results summary report is included as ITAAC item 9 of Table 3.3-1 in DCD Tier 1.

18.11.3 COL Information

None

18.11.4 References

18.11-1 GE Energy, “ESBWR Man-Machine Interface System and Human Factors Engineering Implementation Plan,” NEDE-33217P, Class III (Proprietary), Revision 3, March 2007, and NEDO-33217, Class I (non-proprietary), Revision 3, March 2007.

18.11-2 GE Energy, “ESBWR HFE Verification and Validation Implementation Plan,” NEDO-33276, Class I (non-proprietary), Revision 1, March 2007.

18.12 DESIGN IMPLEMENTATION

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 implementation team executes their responsibilities under the plans described in Reference 18.12-1. The HFE aspects of the ESBWR standard plant including design of the HSIs, standard plant procedures, and baseline training documentation are verified and validated using the Full Scope Simulator 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 resulting from the HFE design process and V&V activities;
- 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; and
- Verify that the resolution of HEDs and open HFE issues are identified and tracked.

The "as-built" confirmations, verifications, and validations described in the Design Implementation plan apply to the 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. These include the corrections and improvements from the HF V&V process.

18.12.2 Methodology of Design Implementation

18.12.2.1 *HSI Verification (As-Built)*

The HSIs and their design characteristics are established in the HSI Design activity using the guidance in the Style Guide for Graphical User Interfaces and issued as the HSI Report. The HSIs are subsequently evaluated and confirmed in the HFE V&V. Following the HFE V&V, the standard plant HSI Report is revised and becomes the basis for the requirements and acceptance criteria for the fabrication/procurement of the equipment for the "as-built" installation. The process and the rationale for the HSI design are documented and managed under GEEN Quality Assurance and ESBWR specific design program plans.

The "as-built" confirmation for the HSIs involves an auditing of the procurement, start-up, and testing process.

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 standard 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 Report. These include:

- Communication equipment interfaces (phones, radios, intercoms, and so forth);
- Lighting (normal and emergency);
- Habitability systems (for example, noise, lighting, ventilation and so forth);
- 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; and
- Procedure/P&ID drawing laydown area.

18.12.2.4 *Resolution of Remaining HEDs and Open issues in 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.

18.12.3 Design Implementation Results Summary Report

The results of the Design Implementation activities are summarized in the RSR. The RSR provides an introduction, background, and summary of results and outputs of the activities performed.

The RSR Design Implementation Plan outputs include:

- Final "as-built" HSI verification;
- Confirmation of procedures and training design implementation;
- Resolution of HEDs and open issues;
- Design implementation team members and background;
- Verification of design not performed in the V&V; and
- Turn over to licensee.

The design implementation results summary report is included as ITAAC item 10 of Table 3.3-1 in DCD Tier 1.

18.12.4 COL Information

None

18.12.5 References

18.12-1 GE Energy, "ESBWR Man-Machine Interface System and Human Factors Engineering Implementation Plan," NEDE-33217P, Class III (Proprietary), Revision 3, March 2007, and NEDO-33217, Class I (non-proprietary), Revision 3, March 2007.

18.12-2 GE Energy, "ESBWR HFE Design Implementation Plan," NEDO-33278, Class I (non-proprietary), Revision 2, January 2007.

18.13 HUMAN PERFORMANCE MONITORING

The HPM strategy links human factors engineering methods used during the design with methods for monitoring human performance during operation. The HPM program and the planned activities to establish it, are provided in the HPM implementation plan, Reference 18.13-2.

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; and
- 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, provide 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; and
  - 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; and
- 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 FSAR.

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, and
- Maintenance and control of updates for:
  - HRA/PRA;
  - Function Requirements Analysis (FRA);
  - Function Allocation (FA);
  - Staffing and Qualifications;
  - HSI changes;
  - Procedures;
  - Training program; and
  - 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; and
- 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 CFR 55.49 and ANSI 3.5).

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); and
- Determining whether the failure is isolated or has generic or common cause implications.

18.13.4 Human Performance Monitoring Results Summary Report

The activities and results of the HPM are summarized in the HPM RSR. The RSR provides the HPM process description, strategies, HFEITS database of events and corrective actions for the life cycle of the plant, along with the analyses that were used.

Other RSR HPM outputs include:

a. Operating data submission to approved committees and agencies; and

b. Periodic issuance of other HPM reports

The HPM results summary report is included as ITAAC item 11 of Table 3.3-1 in DCD Tier 1.

18.13.5 COL Information

None

18.13.6 References

18.13-1 GE Energy, "ESBWR Man-Machine Interface System and Human Factors Engineering Implementation Plan," NEDE-33217P, Class III (Proprietary), Revision 3, March 2007, and NEDO-33217, Class I (non-proprietary), Revision 3, March 2007.

18.13-2 GE Energy, "ESBWR HFE Human Performance Monitoring Implementation Plan," NEDO-33277, Class I (non-proprietary), Revision 2, March 2007.

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.