DESIGN CONTROL DOCUMENT FOR THE US-APWR

Chapter 18
Human Factors Engineering

MUAP- DC018

REVISION 1

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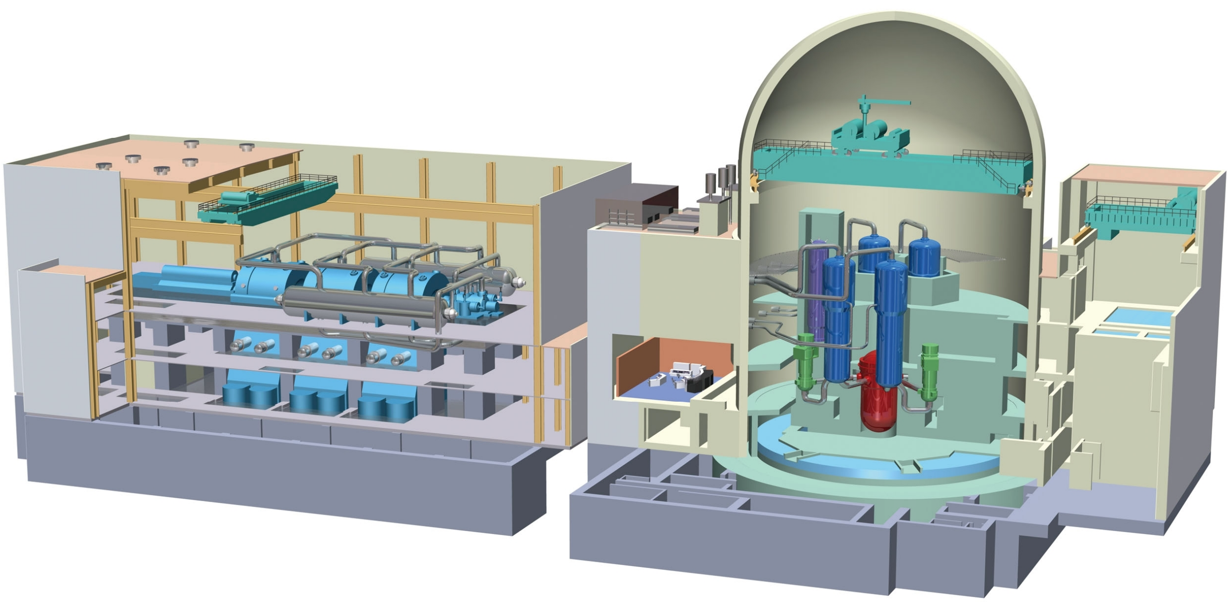

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TABLES

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ACRONYMS AND ABBREVIATIONS

ANS	American Nuclear Society
ANSI	American National Standards Institute
APWR	advanced pressurized-water reactor
BISI	bypassed and inoperable status indication
CAS	central alarm station
CCW	component cooling water
CCWS	component cooling water system
COL	Combined License
CFR	Code of Federal Regulations
CBP	computer-based procedure
CVCS	chemical and volume control system
C/V	containment vessel
DAS	diverse actuation system
DHP	diverse HSI panel
DOE	Department of Energy
DTM	design team manager
ECCS	emergency core cooling system
EFW	emergency feedwater
EOF	emergency operations facility
EOP	emergency operating procedure
ESFAS	engineered safety features actuation system
FA	function allocation
FRA	functional requirements analysis
GDC	General Design Criteria
GOMS	goals, operators, methods, and selection
HA	human action
HED	human engineering discrepancy
HF	human factors
HFE	human factors engineering
HFEVTM	HFE V&V team manager
HRA	human reliability analysis
HSI	human-system interface
HSIS	human-system interface system
HVAC	heating, ventilation, and air conditioning
I&C	instrumentation and control
IAEA	International Atomic Energy Agency
ITV	industrial television

ACRONYMS AND ABBREVIATIONS (Continued)

LCS	local control station
LDP	large display panel
LER	licensee event report
LOCA	loss-of-coolant accident
MCR	main control room
MFW	main feed water
MHI	Mitsubishi Heavy Industries, Ltd.
NRC	U.S. Nuclear Regulatory Commission
NEI	Nuclear Energy Institute
NIS	nuclear instrumentation system
OER	operating experience review
OSD	operational sequence diagram
PAM	post-accident monitoring
PCMS	plant control and monitoring system
PM	project manager
PRA	probabilistic risk assessment
PSF	performance shaping factor
PSMS	protection and safety monitoring system
PWR	pressurized-water reactor
QA	quality assurance
RCP	reactor coolant pump
RCS	reactor coolant system
RG	Regulatory Guide
RHR	residual heat removal
RO	reactor operator
RSC	remote shutdown console
RSR	remote shutdown room
RV	reactor vessel
RWSP	refueling water storage pit
SAS	secondary alarm station
SBO	station blackout
SDCV	specially dedicated continuously visible
SER	significant event report
SFP	spent fuel pit
SG	steam generator
SOER	significant operating experience report
SPDS	safety parameter display system

ACRONYMS AND ABBREVIATIONS (Continued)

SRO	senior reactor operator
STA	shift technical advisor
SW	service water
SWS	service water system
TC	thermo couple
TSC	technical support center
V&V	verification and validation
VDU	visual display unit

18.0 HUMAN FACTORS ENGINEERING

18.1 HFE Program Management

18.1.1 General HFE Program and Scope

The goals of the US-APWR human factors engineering (HFE) program are to ensure that an adequate HFE program is developed and that the program is implemented. The HFE program ensures that each human-system interface (HSI) reflects the latest human factors principles and satisfies the applicable regulatory requirements.

The general objectives of the HFE program are stated in “human centered” terms which, as the HFE program develops, are defined and used as a basis for HFE test and evaluation activities. The specific HFE program goals are:

- Personal tasks are accomplished within the required time and in accordance with specified performance criteria.
- The HSI, procedures, staffing, qualifications, training, and management and organizational support result in a high degree of operating crew awareness of plant conditions.
- The plant design and allocation of functions maintain operational vigilance and provide acceptable workload levels to minimize periods of operator under load and overload.
- The operator interfaces minimize operator error and provide for error detection and recovery capability.

The scope of HFE program management includes the following topics:

- HFE design team and organization
- HFE process and procedures
- HFE issues tracking
- HFE technical program
- Combined license (COL) information

This section documents the execution of the HFE process for each topic.

The US-APWR HFE program is accomplished through the activities implemented by the US-APWR HFE team addressed in Section 18.1. The site specific HFE team follows the US-APWR HFE processes and procedures, Section 18.1.3, for HFE activities assigned to them during the US-APWR design program. The site specific HFE team is responsible for establishing site specific HFE processes and procedures that maintains the certified

US-APWR HFE design in the site-specific as-built plant. The site specific HFE processes and procedures will be used for HSI design changes after the certified US-APWR design responsibility is officially turned over to the site specific HFE Team.

18.1.1.1 Assumptions and Constraints Identification

The assumptions and constraints of the design, such as a specific staffing plan or the use of specific HSI technology inherent in are inputs to the HFE program rather than the result of HFE analyses and evaluations. The design assumptions and constraints are clearly identified. The regulatory requirements applicable to the US-APWR HFE program are listed in Reference 18.1-1, Section 3.0, “Applicable Codes, Standards and Regulatory Guidance”.

A fundamental US-APWR HFE design assumption is that it is possible to operate the plant with just one reactor operator (RO) and one senior reactor operator (SRO) in the main control room (MCR) during postulated plant operating modes (Reference 18.1-1, Section 4.1.f, Design Basis, MCR Staff). This MCR staffing meets the regulatory requirements of 10 CFR 50.54(m)(2)(iii) (Reference 18.1-2). The normal MCR staff is supplemented by one additional SRO and one additional RO that is to be at the plant to accommodate unexpected design conditions, including conditions where the human-system interface system (HSIS) is degraded. This overall plant staffing meets the regulatory requirements of 10 CFR 50.54(m)(2)(i) (Reference 18.1-2). While the HSIS is designed to accommodate the minimum MCR and plant staffing described above, the space and layout of the MCR are designed to accommodate the foreseen maximum number of operating and temporary staff.

Reference 18.1-1 describes the US-APWR HSIS design and the HFE design process. The HSIS has been developed and tested for application in both new and existing operating plants in Japan. The functional requirement specification for the Japanese Advanced Pressurized-Water Reactor (APWR) HSIS design serves as the initial source of input to the HSIS design effort. The US-APWR HSIS design is a direct evolution from the predecessor standard Japanese PWR. However, due to differences between existing Japanese nuclear plants and the US-APWR, and the potential for cross-cultural HFE issues, specific changes in the design are addressed in the US-APWR design.

The development of the integrated US-APWR HSIS, as described in Sections 18.7, 18.8, and 18.9 (“Human-System Interface Design,” “Procedure Development,” and “Training Program Development”), are conducted in an HFE development facility. In addition to HSIS development and testing (Reference 18.1-1, Subsection 5.7.3.3, “HSI Tests and Evaluations”), the verification and validation (V&V) process described in Section 18.10 are conducted in this facility (Reference 18.1-1, Subsection 5.10.2.2.4.b, “Integrated System Validation”, “Validation Test Facility”). This facility provides the updated proof-of-concept testing and “factory testing” described in Reference 18.1-3, Subsection 2.3.2, “Advanced Pressurized-Water Reactor”.

18.1.1.2 Applicable Plant Facilities

The HFE program addresses the following facilities:

- MCR
- Remote shutdown room (RSR)
- Technical support center (TSC)
- Local control stations (LCSs) - consideration of HFE activities for LCSs are limited to those LCSs that support:
  - On-line testing, radiological protection activities, and required chemical monitoring supporting technical specifications
  - Maintenance required by technical specifications
  - Emergency and abnormal conditions response
- Emergency operations facilities (EOFs) (communications and information requirements only)

Overall HFE issues associated with the central alarm station (CAS) and the secondary alarm station (SAS) are discussed in Section 13.6, Security. The HSI Detailed Design and Integration process encompasses the HSI design aspects of the CAS and SAS.

The site specific HFE team is to design the EOF, in accordance with the HFE program. The site specific HFE team is to specify the communication system requirements; however, the US-APWR HFE team determines the EOF information that must be transmitted, in accordance with regulatory requirements and guidance, and incorporates this information in the HFE design (Sections 18.7, 18.8, and 18.9) and the V&V process (Section 18.10). The HSI displays at the EOF include the following:

- SPDS
- Meteorological displays
- Off-site radiation monitoring
- Post accident monitoring

The content of the displays for the EOF is developed based on the task analysis process described in Section 18.4.

18.1.1.3 Applicable HSIs, Procedures and Training

The applicable HSIs, procedures, and training developed and evaluated by the HFE program includes operations, emergency response, maintenance, test, inspection, and surveillance interfaces (including procedures and training provided to operations and maintenance personnel to maintain plant safety and respond to abnormal plant conditions).

18.1.1.4 Applicable Plant Personnel

Plant personnel positions addressed by the HFE program include licensed control room operators as defined in 10 CFR 55 (Reference 18.1-4) and the categories of personnel defined by 10 CFR 50.120 (Reference 18.1-5). These positions are listed and evaluated in Subsection 18.5.2. In addition, any other plant personnel who perform tasks that are directly related to plant safety are addressed by the HFE program.

18.1.1.5 Effects of Modifications on Personnel Performance

The HFE program addresses the need to consider the effects that a plant modification may have on the performance of personnel. For the design certification process, the primary concern is those design changes that have not been fully implemented before V&V has begun. The HFE procedures developed to control V&V are to be in accordance Reference 18.1-6 and are to incorporate controls for evolving designs including re-validation and verification, if required.

18.1.2 HFE Team and Organization

The following section describes the US-APWR HFE design team and organization.

18.1.2.1 HFE Responsibility

The HFE design team for the US-APWR is responsible (with respect to the scope of the HFE program) for the following:

- The development of all HFE plans and procedures
- The oversight and review of all HFE design, development, test, and evaluation activities
- The initiation, recommendation, and provision of solutions for problems identified in the implementation of the HFE activities
- The verification of implementation of team recommendations
- The assurance that all HFE activities comply with the HFE plans and procedures
- The scheduling of activities and milestones

18.1.2.2 HFE Organizational Placement and Authority

The primary HFE organization within the US-APWR program is identified below. The organizational structure to manage the HFE design team is shown in Figure 18.1-1. When more than one organization is responsible for HFE, the lead organizational unit responsible for the HFE program plan is identified. The team has the authority and organizational placement to provide reasonable assurance that all its areas of responsibility are accomplished and to identify problems in the implementation of the overall plant design. The team has the authority to control further processing, delivery, installation, or use of HFE products until the disposition of a nonconformance, deficiency, or unsatisfactory condition has been achieved.

The roles and responsibilities for the key sections of the organization are as follows:

- Project manager (PM)

  The Project Manager assures that the process of design, V&V, and quality assurance (QA) is appropriately implemented in accordance with the HFE implementation plan.

- Design team manager (DTM)

  The design team conducts all design activities for hardware and software. The DTM assures that the design team correctly performs design activities based on the technical requirements and the development process in accordance with Reference 18.1-6. The DTM is also responsible for the following:

  - Initiation, recommendation, and provision for resolutions of problems identified during the implementation of the HFE activities

  - Verification of the effectiveness of the solutions provided to problems

  - Assurance that HFE activities comply with HFE plans and procedures

  - Scheduling of activities

  - Methods for identification, closure, and documentation of human factors issues

  - HSI design and HFE documentation configuration controls

- HFE V&V Team Manager (HFEVTM)

  The HFE V&V team manager is responsible for all activities of the V&V team. The V&V team manager has sufficient resources and authority to ensure that V&V activities are not adversely affected by commercial and schedule pressures. The HFEVTM ensures that the HFE V&Vs are conducted in accordance with the US-APWR HSI V&V implementation plan described in Section 18.10.

- QA Organization

The QA organization conducts the QA in accordance with the QA plan (Reference 18.6-1), which includes conformance to the supplier's overall QA program.

18.1.2.3 HFE Organizational Composition

This section describes the organizational composition of the US-APWR HFE design team.

18.1.2.3.1 HFE Design Organization Composition

The HFE design team conducts all design activities for HSIs. The HFE design team consists of a multi-disciplinary technical staff. The team is under the leadership of an individual experienced in the management of the design and operation of complex control technologies. The technical disciplines of the HFE design team include the following:

- HFE
- Systems engineering
- Nuclear engineering
- Instrumentation and control (I&C) engineering
- Architect engineering
- Plant operations
- Computer system engineering
- Plant procedure development
- Personnel training
- Systems safety engineering
- Maintainability/inspectability engineering
- Reliability/availability engineering

The term "HFE design team" is used in a generic sense to refer to the personnel who are contributors for HFE design. Many of the technical disciplines listed above are assigned to support HFE on a "matrixed" basis, but report organizationally through other technical groups. An organization representing a cadre of HFE professionals is contained in a single organization with a responsible manager and contains, at the minimum, the following HFE design disciplines:

- HFE
- Personnel training
- Plant procedure development
- Plant operations

These HFE disciplines are organized into groups. Each group is under a technical leader who reports to the HFE DTM. These groups are mutually supporting to produce an integrated HFE design product for the US-APWR and have access to other engineering support, as needed, and may be augmented by subcontractor support, as the workload requires. These groups work in an integrated fashion in the development of scenarios for human reliability analysis (HRA) evaluations, task analyses, HSI tests and evaluations, validation, and other HFE-related evaluations.

18.1.2.3.1.1 HFE

This group performs human factors analyses, develops human factors designs based on human factors principles, guidelines, and standards, and participates in the resolution of identified human factors problems.

18.1.2.3.1.2 Personnel Training

This group develops content and format for personnel training programs for licensed and non-licensed plant personnel and coordinates training issues arising from activities such as HRA, HSI design, and procedure design.

18.1.2.3.1.3 Plant Procedure Development

This group develops operating and emergency operating procedures (EOPs), procedure aids, and computer-based procedures (CBPs), based on analysis of operational tasks. The group establishes procedure formats, based on emergency procedure guidelines and operational procedures from current and predecessor plants.

18.1.2.3.1.4 Plant Operations

The plant operations group is organized to simulate the nuclear plant shift staff for the HSI development process and subsequent V&V process. The group interfaces with the other HFE groups, simulator operations personnel, and the I&C design groups to provide a highly capable control system development infrastructure.

The US-APWR is intended to be operated, in its normal mode, by one SRO and one RO in the MCR with other operating staff available at the plant to augment the minimum staff during abnormal plant conditions and degraded HSI conditions. The plant operations group is staffed and trained to support analysis of these plant configurations.

The minimum operator staffing structure is shown in Figure 18.1-2.

The plant operations group has sufficient personnel to support maximum continuous staffing in the MCR, as shown is Figure 18.1-3.

The plant operations group provides practical nuclear plant operating knowledge to the other HFE groups so that HSIs are fully integrated. This group provides knowledge of operational activities including task characteristics, HSI characteristics, environmental characteristics, and technical requirements related to operational activities. This group acts as an information resource in support of other HSI design activities, obtaining and evaluating engineering information for the HSI development, procedures, and training groups.

18.1.2.3.2 HFE V&V Team Organization Composition

The V&V team conducts the HFE V&Vs in accordance with the US-APWR HSI V&V implementation plan (Section 18.10). The V&V team includes personnel with the following technical skills:

- HFE
- Plant operations
- Operator training
- HSI design

The V&V team adds other technical disciplines as needed during the V&V process.

18.1.2.4 HFE Organizational Staffing

The HFE team staffing is described in terms of minimum qualifications and job descriptions of team personnel. The minimum qualifications and job descriptions of team personnel are documented, and controlled as required by Reference 18.1-6.

The requisite professional experience is satisfied by the HFE design team as a collective whole. Therefore, the satisfaction of the professional experience requirements associated with a particular skill area may be realized through the combined professional experience of two or more members of the HFE design team who each, individually, satisfies the other defined credentials of the particular skill area but who does not possess all of the specified professional experience. It is recognized that one person may possess multiple skills and that people may have additional responsibilities beyond the HFE design team. The roles and responsibilities for the key sections of the organization are described in Reference 18.1-1 Subsection 5.1.2.2.

Alternative personal credentials may be accepted as the basis for satisfying the minimum personal qualification. Acceptance of such alternative personal credentials is evaluated on a case-by-case basis and approved, documented, and retained in auditable project files as described in Reference 18.1-6.

18.1.3 HFE Process and Procedures

Activities performed relating to HFE are performed in accordance with documented procedures under the QA Program for the US-APWR (Reference 18.1-6). These procedures provide the control over the HFE processes as described below.

18.1.3.1 General Process Procedures

The processes through which the team executes its responsibilities include procedures for:

- Assigning HFE activities to individual team members
- Governing the internal management of the team
- Making management decisions regarding HFE
- Making HFE design decisions
- Governing equipment design changes
- Design team review of HFE products

All HFE processes and procedures are developed and performed as described in Reference 18.1-6.

18.1.3.2 Process Management Tools

Tools and techniques (e.g., review forms) to be utilized by the team to verify that they fulfill their responsibilities are identified. HFE analytical procedure and associated engineering documentation are developed and controlled as described in Reference 18.1-6.

18.1.3.3 Integration of HFE and Other Plant Design Activities

The integration of design activities identifies, the inputs from other plant design activities to the HFE program and the outputs from the HFE program to other plant design activities. The iterative nature of the HFE design processes is addressed. HFE design controls are as described in Reference 18.1-6.

18.1.3.4 HFE Program Milestones

HFE milestones are identified so that evaluations of the effectiveness of the HFE effort can be made at critical checkpoints and the relationship to the integrated plant sequence of events is shown. A relative program schedule of HFE tasks showing relationships between HFE elements and activities, products, and reviews has been developed (Reference 18.1-1).

18.1.3.5 HFE Documentation

Controlled HFE design documents are identified and briefly described, and the procedures for retention and access of these documents are defined. HFE document control is as described in Reference 18.1-6.

18.1.3.6 Subcontractor HFE Efforts

HFE requirements are included in each subcontract for HFE support and the subcontractor's compliance with HFE requirements is periodically verified. HFE work performed by subcontractors is controlled as described in Reference 18.1-6.

18.1.4 HFE Issues Tracking

The HFE issues tracking system is integrated into the existing tracking system used for the US-APWR design effort as a whole. The HFE issues tracking system is available to address human factors issues that are (a) known to the industry and (b) identified throughout the HFE life cycle of HSI design, development, and evaluation.

The HFE issues tracking system provides a mechanism to address the items that need to be addressed later in the project and must not be overlooked. The HFE issue tracking system provides assurance that HFE issues are tracked from identification until the potential for negative effects on human performance has been reduced to an acceptable level.

The HFE issues and concerns that are not immediately resolved are entered in the HFE issues tracking system. The HFE design team members are responsible for issue logging, tracking, resolution, and resolution acceptance. Human performance issues that are identified as human engineering discrepancies (HEDs) are tracked and dispositioned as required by Reference 18.1-6.

Each action taken to eliminate or minimize an HFE issue or concern is documented in detail. Both the HFE design team's final resolution of the HFE/HSI issue and the resolution's acceptance are documented.

The process through which the HFE design team executes its responsibilities is described in Reference 18.1-1 Subsection 5.1.3.

18.1.5 HFE Technical Program

The HFE technical program is performed in accordance with the HFE process specified in NUREG-0711 (Reference 18.1-7). The general development of each of the elements of the HFE technical program, including the associated implementation plans, analyses, and evaluation, is identified and described in Figure 18.1-4. The program's eleven elements are as follows:

- Operating experience review (OER)
- Functional requirements analysis and function allocation
- Task analysis
- Staffing and qualifications
- HRA
- HSI design
- Procedure design
- Training design
- Human factors verification and validation
- Design implementation
- Human performance monitoring

The HFE standards and specifications, which are sources of HFE requirements imposed on the design process, are identified and described in Reference 18.1-1, Chapter 3.0, "Applicable Codes, Standards and Regulatory Guidance".

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

- Analyze steady state and transient behavior
- Confirm the design of the advanced alarm system concepts
- Confirm the adequacy of control schemes
- Confirm the allocation of control functions to a system or an operator
- Develop and validate plant operating procedures

- Incorporate into the plant design, as effectively as possible, the utilization of full-scope or limited-use simulators

Part-task or engineering modeling/simulation is used to develop an initial set of plant control parameters, including the development of associated graphical user interfaces. The part-task simulator is used in the preliminary US-APWR design and then expanded to include specific US-APWR design features. As the US-APWR design progresses, the part-task simulator proceeds through a series of iterative evaluations, resulting in the development of a full-scope control room simulator. As described in Subsection 18.1.1.1, the simulator facility is the focal point for HFE development, engineering design verification, and operator evaluations/validation throughout the HSI design process.

Modifications to the US-APWR approved HSI design meet current regulations, except where specific exemptions are requested under 10 CFR 50.12 (Reference 18.1-8) or 10 CFR 2.802 (Reference 18.1-9), and are controlled as described in Reference 18.1-6.

Modifications to the US-APWR approved HSI design will not compromise defense-in-depth. Defense-in-depth is one of the fundamental principles upon which the plant will be designed and built. Defense-in-depth is important in accounting for uncertainties in equipment and human performance, and for ensuring that some protection remains even in the face of significant breakdowns in particular areas. Defense-in-depth elements may be changed, but should be maintained overall. The following important aspects of defense-in-depth, as identified in Regulatory Guide (RG) 1.174 (Reference 18.1-10), are maintained throughout the US-APWR design:

- A reasonable balance is preserved among prevention of core damage, prevention of containment failure, and consequence mitigation.

- There is no over-reliance on programmatic activities to compensate for weaknesses in plant design. This may be pertinent to changes in credited human actions (HAs).

- System redundancy, independence, and diversity are preserved commensurate with the expected frequency, consequences of challenges to the system, and uncertainties (e.g., no risk outliers).

- Defenses against potential common cause failures are preserved, and the potential for the introduction of new common cause failure mechanisms is assessed. Caution is exercised in crediting new HAs to verify that the possibility of significant common cause errors is not created.

- Independence of barriers is not degraded.

- Defenses against human errors are preserved. For example, 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 10 CFR Part 50, Appendix A (Reference 18.1-11), is maintained. The GDC that are relevant are as follows:
  - GDC 3 – Fire Protection
  - GDC 13 – Instrumentation and Control
  - GDC 17 – Electric Power Systems
  - GDC 19 – Control Room
  - GDC 34 – Residual Heat Removal
  - GDC 35 – Emergency Core Cooling System
  - GDC 38 – Containment Heat Removal
  - GDC 44 – Cooling Water
- Safety margins are often used in deterministic analyses to account for uncertainty and incorporate an added margin to provide adequate assurance that the various limits or criteria important-to-safety is not violated.

The technical information generated from the HFE program activities are documented in technical reports covering the associated sections of this chapter:

- HFE Analysis – Sections 18.2, 18.3, 18.4, 18.5, and 18.6
  - Section 18.2 – US-APWR operating experience review report
  - Section 18.3 – functional requirements analysis/function allocation (FRA/FA) report
  - Section 18.4 – task analysis report
  - Section 18.5 – staffing and qualifications analysis report
  - Section 18.6 – HFE/HRA integration report
- HFE Design – Sections 18.7, 18.8, and 18.9
  - Section 18.7 – HSI Design Technical Report
  - Section 18.8 – US-APWR procedure system report
  - Section 18.9 – training program report
- HFE Verification and Validation – Section 18.10

- Section 18.10 – U.S. Operator V&V Technical Report (Phase 1) and US-APWR HF V&V Report (Phase 2)

18.1.6 Combined License Information

No additional information is required to be provided by a COL Applicant in connection with this section.

COL 18.1(1) Deleted

COL 18.1(2) Deleted

18.1.7 References

18.1-1 HSI System Description and HFE Process, MUAP-07007-P (Proprietary) and MUAP-07007-NP (Non-Proprietary), Revision 1, July 2007.

18.1-2 Conditions of Licenses, NRC Regulations Title 10, Code of Federal Regulations, Part 50.54.

18.1-3 Wood, R. T., et al., Advanced Reactor Licensing: Experience with Digital I&C Technology in Evolutionary Plants, NUREG/CR-6842, March 2004.

18.1-4 Operators' Licenses, NRC Regulations Title 10, Code of Federal Regulations, Part 55.

18.1-5 Training and Qualification of Nuclear Power Plant Personnel, NRC Regulations Title 10, Code of Federal Regulations, Part 50.120.

18.1-6 Quality Assurance Program (QAP) Description for Design Certification of the US-APWR, PQD-HD-19005, Revision 1, Mitsubishi Heavy Industries, Ltd., October 2007.

18.1-7 Human Factors Engineering Program Review Model, NUREG-0711, Revision 2, U.S. Nuclear Regulatory Commission, Washington, DC, February 2004.

18.1-8 Specific Exemptions, NRC Regulations Title 10, Code of Federal Regulations, Part 50.12.

18.1-9 Petition for Rulemaking, NRC Regulations Title 10, Code of Federal Regulations, Part 2.802.

18.1-10 An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis, Regulatory Guide 1.174, Revision 1, November 2002.

18.1-11 General Design Criteria for Nuclear Power Plants, NRC Regulations Title 10, Code of Federal Regulations, Part 50, Appendix A.

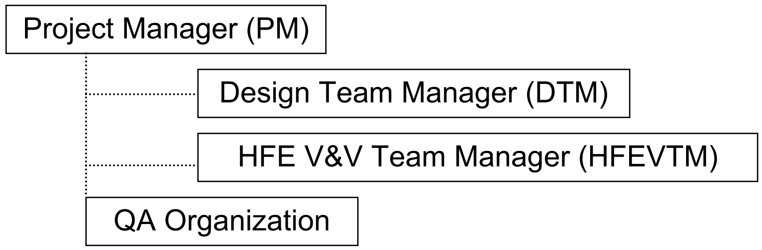
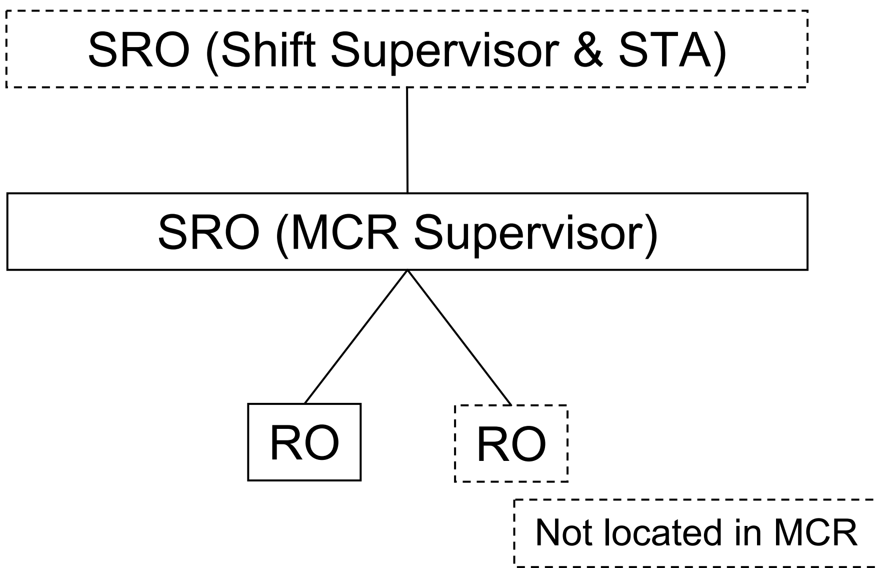


Figure 18.1-1 Organization of HFE Design Team



Note: STA: shift technical advisor

Figure 18.1-2 Operations Personnel Staffing and Organization (Minimum)

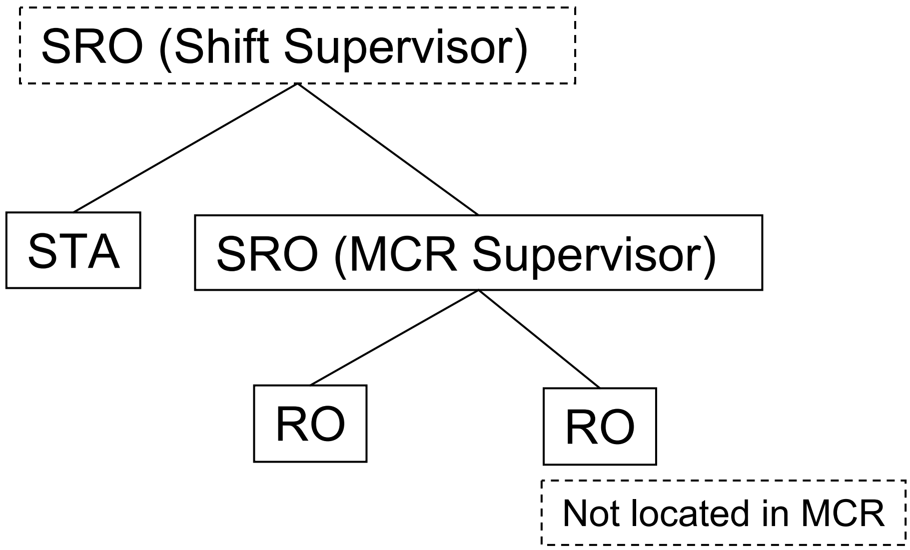


Figure 18.1-3 Operations Personnel Staffing and Organization (Typical)

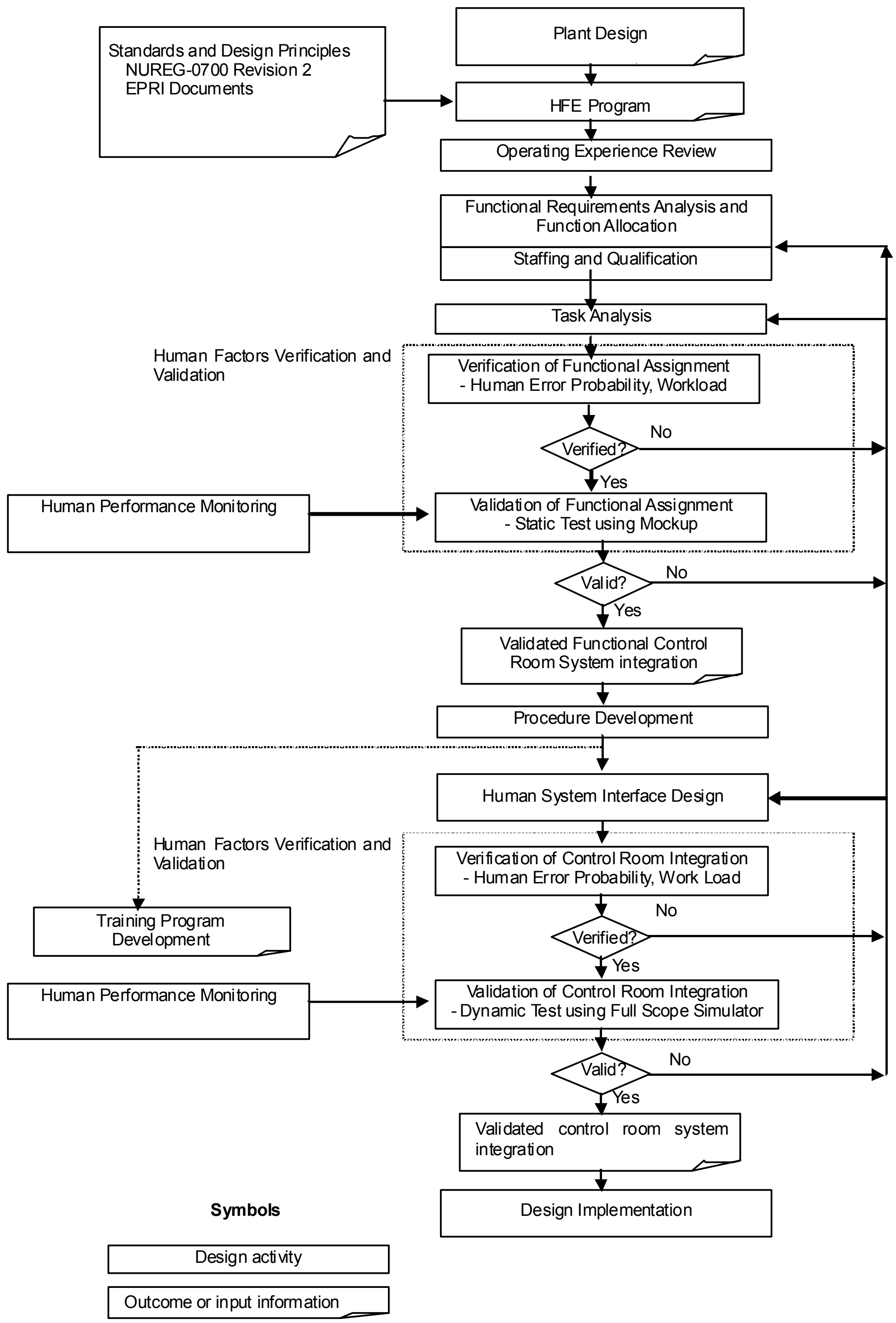


Figure 18.1-4 Overall HFE Design Process

18.2 Operating Experience Review

18.2.1 Objectives and Scope

The objective of the HFE OER is to identify and analyze HFE-related problems and issues encountered in previous nuclear plant designs that are similar to the US-APWR, so that the negative features are not repeated and the positive features are retained. Since the nuclear industry lacks significant experience with the modern HSI technology used in the US-APWR, the OER also encompasses the utilization of similar HSI technologies from other process industries.

This review includes information pertaining to the human factors issues related to the predecessor plant(s) or highly similar plants and plant systems. Recognized nuclear industry HFE issues and the issues related to HFE technology are included in the review. Issues related to advanced reactor design, as contained in Reference 18.2-1, are addressed. Personnel interviews have been conducted to determine operating experience related to predecessor plants or systems. The OER identifies risk-important HAs that have been identified as different or where errors have occurred.

The OER is documented in US-APWR operating experience review report. The detailed methodology for performing the HFE OER and integrating it into the HFE analyses is described below.

18.2.2 Methodology

18.2.2.1 OER Process

OER is the examination and evaluation of specific in-house and industry-operating experience related to system and human performance for systems similar to the system under reviewed. The technique entails the review of the following data sources:

- Licensee event reports (LERs)
- Significant event reports (SERs)
- Significant operating experience reports (SOERs)
- Plant corrective action systems
- Operational and maintenance logs and records
- Data from interviews with experienced plant personnel

A structured evaluation is conducted to determine the applicability of the operational data to each human factors issue. This evaluation is performed by an HFE team of subject matter experts drawn from the technical disciplines described in Section 18.1. The evaluation data and process are recorded on a form, as shown in Reference 18.2-2,

Table 5.2-1. Issues identified during the OER were analyzed by methods described in Sections 18.3, 18.4, 18.5, and 18.6 with regard to the identification of the following:

- Human performance issues, problems, and sources of human error
- Design elements that support and enhance human performance

Each operating experience item determined by analysis to be appropriate for incorporation in the design (but not already addressed in the design) is documented in the HFE issues tracking system, as described in Reference 18.2-2, Subsection 5.1.4. Appropriate design analysis and modifications are conducted, as described in Sections 18.7, 18.8, and 18.9.

18.2.2.2 Predecessor Plants and Systems

The HSI for the US-APWR is based on the following predecessor plant designs:

- Japanese conventional 3-loop PWR with full digital I&C and HSI: this plant is under construction
- Japanese 4-loop APWR with full digital I&C and HSI: this plant is under licensing
- Japanese conventional 2-loop PWR with full digital I&C and HSI modernization: this plant is under licensing

All of these plants utilize the same standard HSI design that is used in the US-APWR. The OER process for this standard HSI design and the expanded OER that led to the HSI design for the US-APWR is shown in Figure 18.2-1.

The contribution of the OER process to the standard Japanese PWR HSI design includes two major operating experience inputs:

- LERs and SERs from the currently operating Japanese PWRs
- Plant corrective action systems, operating logs, and maintenance logs from the currently operating Japanese PWRs

The standard Japanese PWR HSI design is the predecessor of the US-APWR HSI design. The US-APWR also reflects an expansion of the OER that includes the following:

- LERs for US nuclear reactors, as described in Reference 18.2-1 (described in Subsection 18.2.2.5)
- LERs and SERs for US nuclear reactors that have been issued since the issuance of Reference 18.2-1

- The plant corrective action systems, operating logs, and maintenance logs from US plants currently operated by anticipated US-APWR licensees.

The following are the key differences between the standard Japanese PWR HSI and the HSI for the US-APWR:

- Arrangement of the main control room operator console to accommodate the change from one to two reactor operator stations
- Accommodating the change from two-train to four-train design
- HSI details to accommodate specific plant mechanical and electrical systems
- Japanese to English language conversion
- Metric to English units conversion
- Ergonomics changes to operator consoles to accommodate American personnel

The HFE design aspects incorporated in the US-APWR from previous or predecessor plant designs are clearly identified in the US-APWR operating experience review report. The HFE-related problem resolutions, including supporting analysis and corrective designs are provided. In addition, a discussion of positive HFE features that were identified, evaluated, and retained is provided.

18.2.2.3 Risk-Important Human Actions

The OER identifies risk-important HAs from the predecessor plants that are also applicable to the US-APWR. The OER provides justification for risk-important HAs from predecessor plants that are not applicable. The HAs are entered into the US-APWR issues tracking system to ensure they receive special attention during the design process to lessen their probability of occurrence.

18.2.2.4 HFE Technology

The OER addresses related HFE technology. For example, touch screen interfaces, large-screen wall panel displays, electronic maintenance tagging systems, and computerized procedures are utilized in the standard Japanese PWR HSI and the US-APWR HSI, as described in Reference 18.2-2. HFE issues associated with their use are reviewed, including HFE design aspects used in other industries. There are no technology differences between the standard Japanese PWR HSI and the US-APWR HSI.

18.2.2.5 Recognized Industry Issues

The recognized industry issues contained in Reference 18.2-1 and issues subsequent to the publication of Reference 18.2-1 are addressed. These issues are organized into the following categories:

- Unresolved safety issues/generic safety issues
- Three Mile Island issues
- NRC generic letters and information notices
- Reports of the former NRC Office for Analysis and Evaluation of Operational Data
- Low power and shutdown operations
- Operating plant event reports

18.2.2.6 Issues Identified by Plant Personnel

Personnel interviews were conducted to determine operating experience related to predecessor plants or systems. Interview feedback was provided in the following topics areas:

- Plant Operations
  - Normal plant evolutions (e.g., startup, full power, and shutdown)
  - Instrument failures (e.g., safety-related system logic and control unit, fault tolerant controller (nuclear steam supply system), data network bus system, network bus controller, and break in data network line)
  - HSI equipment and processing failure (e.g., loss of video display units, loss of data processing, or loss of large overview display)
  - Transients (e.g., turbine trip, loss of offsite power, station blackout, loss of all feedwater, loss of service water, loss of power to selected buses or control room power supplies, and safety/relief valve transients)
  - Accidents (e.g., main steam line break, positive reactivity addition, control rod insertion at power, control rod ejection, anticipated transients without scram, and various-sized loss-of-coolant accidents)
  - Reactor shutdown and cooldown using remote shutdown system
- HFE Design Topics
  - Alarm and annunciation
  - Display
  - Control and automation

- Information processing and job aids
- Real-time communications with plant personnel and other organizations
- Procedures, training, staffing/qualifications, and job design

18.2.2.7 Issue Analysis, Tracking, and Review

Issues identified during the OER are entered into the HFE issues tracking system. Each OER item that is determined by analysis to be appropriate for incorporation in the design is documented in the HFE issues tracking system, as described in Reference 18.2-2, Subsection 5.1.4. The HFE issues tracking system provides the appropriate level of reviews to ensure that issues are tracked to completion.

18.2.3 Results

The results from the HFE OER analysis are documented in the US-APWR operating experience review report. Issues identified during the OER are incorporated, and issue analysis results and associated design changes are documented. Table 18.2-1 provides several examples of issues and resolutions extracted from the Technical Report . (Reference 18.2-3)

18.2.4 Combined License Information

No additional information is required to be provided by a COL Applicant in connection with this section.

18.2.5 References

18.2-1 Higgins, J. and Nasta, K., HFE Insights For Advanced Reactors Based Upon Operating Experience, NUREG/CR-6400, December 1996.

18.2-2 HSI System Description and HFE Process, MUAP-07007-P (Proprietary) and MUAP-07007-NP (Non-Proprietary), Revision 1, July 2007.

18.2-3 U.S. Operator V&V Technical Report (Phase 1 V&V), MUAP-08XXX-P (Proprietary) and MUAP-08XXX-NP (Non-Proprietary), later.

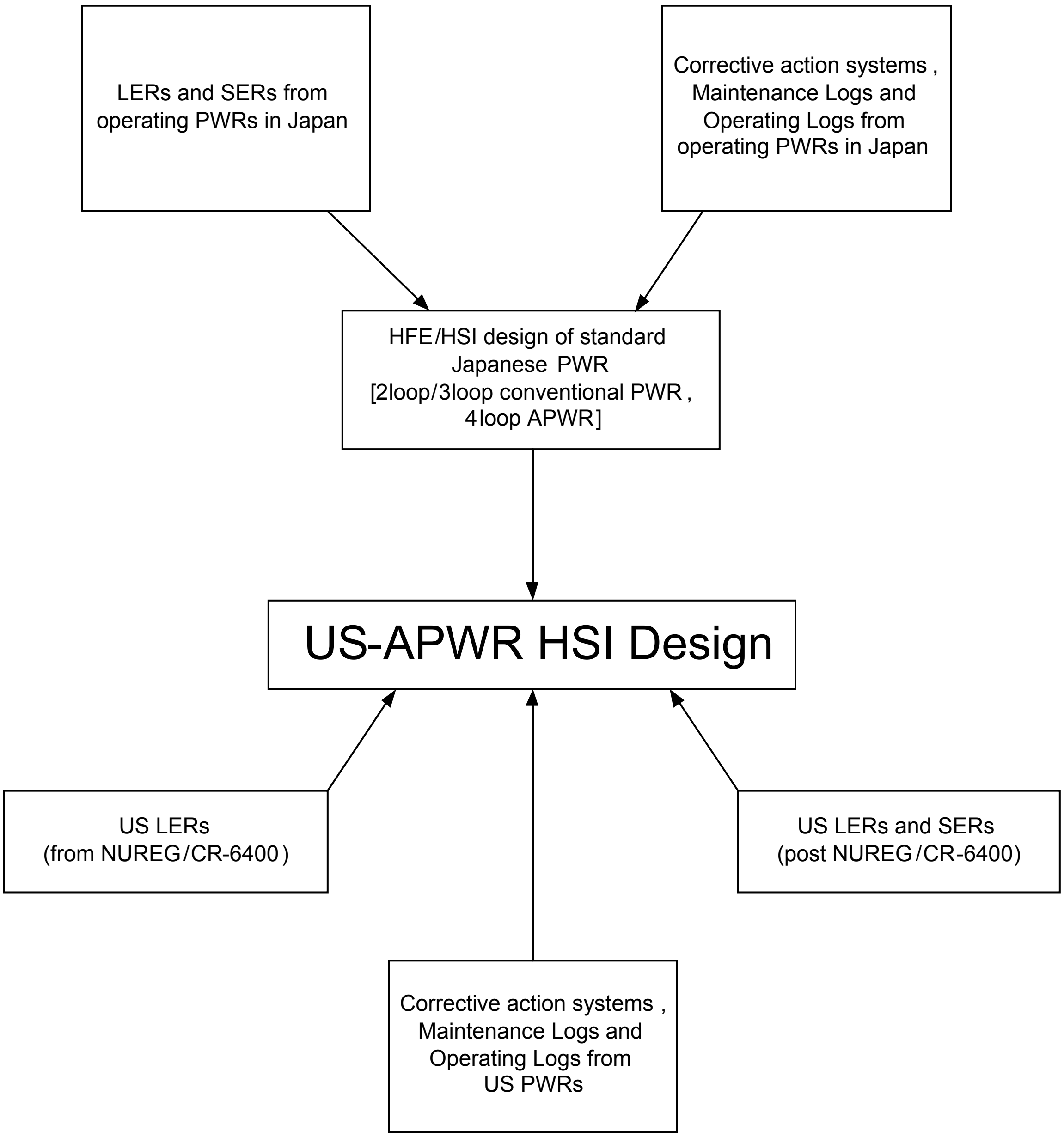


Figure 18.2-1 US-APWR OER Process

Table 18.2-1 Examples of Issues and Resolutions from US-APWR OER Report (Sheet 1 of 3)

No.	Item	Issue/Scope	Human Factors Aspect Issue	Human Factors Issue addressed by US-APWR
1	A-44	Station blackout (SBO)	This is a large and significant issue with many human factors-related aspects, including controls, displays, training, and procedures.	In US-APWR, safety I&C system allows operators to maintain longer term hot shut down condition and transition and maintain cold shutdown. Safety grade HSI system provides all safety component controls and monitoring of safety functions, and provides all safety related plant information to operators. Safety I&C system power, including safety grade HSI system, is supplied by a class 1E safety grade voltage line which power on at least one train cannot be lost under SBO condition. Safety HSI system is located at the operator console in the MCR and at the remote shutdown console outside of MCR. In addition, though it is not necessary to maintain the power supply for safety shutdown transition, non safety HSI system is also available for thirty minutes under SBO condition.
2	A-47	Safety implications of control systems	This issue relates to the implications of failures of non safety-related control systems and their interaction with control room operators.	MUAP-07004-P, "Safety I&C System Description and Design Process" Subsection 5.1.8 ensures non safety system failure does not affect the safety system which credits plant safety functions. The implications of failures of non safety-related control systems and their interaction with control room operators are addressed in "HSI System Description and HFE Process" Section 4.11, "Response to HSI Equipment Failures".

Table 18.2-1 Examples of Issues and Resolutions from US-APWR OER Report (Sheet 2 of 3)

No.	Item	Issue/Scope	Human Factors Aspect Issue	Human Factors Issue addressed by US-APWR
3	B-17	Criteria for safety-related operator actions	This issue involves the development of a time criterion for safety-related operator actions including a determination of whether automatic actuation is required. This issue also concerns some current pressurized water reactor designs requiring manual operations to accomplish the switchover from the injection mode to the recirculation mode, after a loss-of-coolant accident (LOCA).	Defense-in-depth and diversity coping analysis provides a time criterion for safety-related operator actions. In accordance with this analysis, if actions are needed earlier than 10 minutes, the function is generally automated. Any operator actions credited prior to 30 minutes are justified based on EOP and task analysis. Transfer actions from the injection mode to the recirculation mode after LOCA are generally automated.
4	B-32	Ice effects on safety-related water supplies	The buildup of ice on service water intakes can occur gradually and can require improved instrumentation to allow operators to detect its occurrence before it causes system inoperability.	The service water temperature is monitored and alarmed in MCR at low temperature setpoint.
5	GI-2	Failure of protective devices on essential equipment	A large number of licensee event reports have noted the incapacitation of safety-related equipment because of the failure of protective devices such as fuses and circuit breakers. Operators are not always aware of the failure of the equipment because of the design of the instrumentation.	To minimize the effects of failures of safety-related equipment, the following measures are applied; - I&C systems including non safety system are extensively distributed and digitalized. These digital I&C systems have a self-diagnosis function for their failures. - Redundant safety equipment power is supplied by independent power source. In addition, their failure is monitored and alarmed in the MCR.

Table 18.2-1 Examples of Issues and Resolutions from US-APWR OER Report (Sheet 3 of 3)

No.	Item	Issue/Scope	Human Factors Aspect Issue	Human Factors Issue addressed by US-APWR
6	GI-23	Reactor coolant pump seal failures	This is a multifaceted issue, which includes a number of proposed resolutions. One sub issue is the provision of adequate seal instrumentation to allow the operators to take corrective actions to prevent catastrophic failure of seals (see Subsection 7.3.1 for more detail).	RCP seal flow and boundary on each RCP seal are monitored and alarmed at abnormal status in MCR. RCP seal leak and rupture event is analyzed and the procedures are prepared.
7	GI-51	Improving the reliability of open cycle service water (SW) systems	The buildup of clams, mussels, and corrosion products can cause the degradation of open cycle SW systems. Added instrumentation is one means of providing operators with the capability to monitor this buildup and take corrective action before loss of system functionality occurs.	SW system has instrumentation that detects its flow degradation. The low flow alarm informs operators of service water system (SWS) degradation and operators can take corrective actions.

18.3 Functional Requirements Analysis and Function Allocation

18.3.1 Objectives and Scope

The objective of the functional requirements analysis and function allocation is to ensure that the safety functions of the US-APWR are assigned properly as HAs or to automated systems. The safety functional requirements are defined in such a way that the functional allocations take advantage of human strengths and avoid allocating functions that would be negatively influenced by human limitations. The functional requirements analysis and function allocation is based on that performed for the Japanese APWR design, with additional analyses performed to address the differences in the US-APWR design.

18.3.1.1 Functional Requirements Analysis

The scope of the functional requirements analysis includes the identification of functions that must be performed to satisfy plant safety objectives; that is, to prevent or mitigate the consequences of postulated accidents that could damage the plant or cause undue risk to the health and safety of the public. A functional requirements analysis is conducted to:

- Determine the objectives, performance requirements, and constraints of the design
- Define the high-level functions that have to be accomplished to meet the design’s objectives and desired performance
- Define the relationships between high-level functions and plant systems (e.g., plant configurations or success paths) responsible for performing the function
- Provide a framework for understanding the role of controllers (whether personnel or system elements) for controlling the plant

18.3.1.2 Function Allocation Analysis

The scope of the function allocation activity includes the analysis of the requirements for plant control and the assignment of control functions for the following:

- Personnel (e.g., manual control)
- System elements (e.g., automatic control or passive, self-controlling phenomena)
- Combinations of personnel and system elements (e.g., shared control or automatic systems with manual backup)

Plant safety and reliability are enhanced by exploiting the strengths of personnel and system elements, including improvements that can be achieved through the assignment of control to these elements with overlapping and redundant responsibilities. In addition to technological and economic considerations, function allocation should be based on HFE principles using a structured and well-documented methodology that seeks to provide personnel with logical, coherent, and meaningful tasks. Function allocation should not be based solely on technology considerations that allocate to plant personnel everything the designers cannot automate, because such an approach results in an ad hoc set of activities that may negatively affect operator performance.

The FA includes credited manual operator actions identified in the plant accident analysis. They include manual alignment actions that may be necessary during emergency core cooling system (ECCS) operation in accident sequences up through the time of long-term cooling, as described in Section 6.3 Emergency Core Cooling Systems, Subsection 6.3.2.8 “Manual Actions”.

18.3.2 Methodology

The detailed methodology for conducting the functional requirements analysis and function allocation and integrating it into the HFE analyses is documented in this section.

18.3.2.1 Methodology for Functional Requirements Analysis

Functional requirements analysis and function allocation are performed using a structured, documented methodology reflecting HFE principles. Reference 18.3-1, Section 3, provides general guidance on conducting the functional design of a nuclear power plant control room. Detailed guidance on the analytical methodology used is provided in Reference 18.3-1, Appendix A.3. Additional detailed information on function allocation is focused in Reference 18.3-2 to supplement Reference 18.3-1, as required. Reference 18.3-3, Subsection 5.3.2, provides the criteria that Mitsubishi Heavy Industries, Ltd. (MHI) employed in determining function allocation for the reference plants.

The MHI functional requirements hierarchical structure employed for the reference nuclear plant control rooms is shown in Reference 18.3-3, Figure 5.3-1. The hierarchy shows the functions essential to plant safety, and specific emergency and accident events that may affect each plant safety function, and the components that affect each emergency and accident event. The experience gained from the reference plant functional allocation has been incorporated into the US-APWR control room design.

The functional requirements analysis and function allocation is conducted based on the following:

- The degree to which the functions of the new design differ from those of the predecessor
- The extent to which difficulties related to plant functions were identified in the plant’s operating experience and are addressed in the new design

The functional requirements analysis and function allocation are kept current over the life cycle of design development and are maintained until decommissioning, so that they can be used as design base when modifications are considered. Control functions are re-allocated in an iterative manner, in response to developing design specifics, operating experience, and the outcomes of ongoing analyses and trade studies, if required.

The OER (Section 18.2) is used to identify modifications to function allocations, if necessary. If problematic OER issues are identified, then an analysis should be performed to:

- Justify the original analysis of the function
- Justify the original human-machine allocation
- Identify solutions such as training, personnel selection, and procedure design that is to be implemented to address the OER issues

18.3.2.2 Methodology for Function Allocation Analysis

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

The functional requirements analysis and function allocation verifies the following:

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

The FRA/FA is kept current with design changes and the HFE issues tracking program, as described in Subsection 18.10.2.4 and Section 18.11.

18.3.3 Results

The results of the functional requirements analysis and function allocation is documented in the Technical Report (Reference 18.3-4). The Technical Report includes a description of the functions and systems, along with a comparison to the reference plants/systems (i.e., the previous plants or plant systems on which the US-APWR systems are based). This description identifies differences that exist between the US-APWR and reference plants/systems. A description of the integrated personnel role across functions and systems is provided in terms of personnel responsibility and level of automation.

A description is provided for each safety function (e.g., reactivity control). The safety functions include functions needed to prevent or mitigate the consequences of postulated accidents that could cause undue risk to the health and safety of the public. For each safety function, the set of plant system configurations or success paths that are responsible for or capable of carrying out the function is clearly defined. Function decomposition starts at “top-level” functions where a very general picture of major functions is described, and continue to lower levels until a specific critical end-item requirement emerges (e.g., a piece of equipment, software, or HA). The functional decomposition addresses the following levels:

- High-level functions (e.g., maintain Reactor Coolant System integrity) and critical safety functions (e.g., maintain Reactor Coolant System pressure control)
- Specific plant systems and components

A description is provided for each high-level function and includes the following:

- Purpose of the high-level function
- Conditions that indicate that the high-level function is needed
- Parameters that indicate that the high-level function is available
- Parameters that indicate the high-level function is operating (e.g., flow indication)
- Parameters that indicate the high-level function is achieving its purpose (e.g., reactor vessel level returning to normal)
- Parameters that indicate that operation of the high-level function can or should be terminated (parameters may be described qualitatively (e.g., high or low) since specific data values setpoints are not necessary at this stage)

A detailed description of differences in high-level functions, and the technical basis, between the current Japanese PWR design and the US-APWR design is provided in the Technical Report.

The major FA changes for the US-APWR as compared to the standard Japanese PWR plants are to re-allocate manual actions to automatic actions for:

- Automatic isolation of a failed steam generator (SG)
- Automatic establishment of recirculation for ECCS

The functional details are described in the FRA/ FA report. The re-allocations of actions are as follows:

- An automatic isolation of a failed SG
  - The purpose of the FA changes is to reduce plant operator workload and potential human error when responding to a failed SG. Emergency feedwater isolation valves should be closed in case the SG level and steam pressure

reach the setpoint that will result in a low SG inventory. The SG levels and pressures are significant parameters for monitoring the SG conditions.

- Automatic establishment of recirculation for ECCS
  - The purpose of the FA changes is to allocate establishment of long-term core cooling after the LOCA from manual to automatic action. In the design of a present day PWR plant, a containment recirculation sump water level is an essential parameter in changing recirculation mode. The US-APWR refueling water storage pit inside containment enables ECCS recirculation to be established automatically.

The technical basis for each function allocation is documented, including the allocation criteria, rationale, and analyses method. The technical basis for functional allocation can be any one or a combination of evaluation factors (Reference 18.3-3, Figure 5.3-1). For example, the performance demands to successfully achieve the function, such as the degree of sensitivity needed, precision, time, or frequency of response, may be so stringent that it would be difficult or error prone for personnel to accomplish. This establishes the basis for automation (assuming acceptability of other factors, such as technical feasibility or cost) and is described in Reference 18.3-3, Subsection 5.3.2.

18.3.4 Combined License Information

No additional information is required to be provided by a COL Applicant in connection with this section.

COL 18.3(1) Deleted

COL 18.3(2) Deleted

18.3.5 References

18.3-1 Design for Control Rooms of Nuclear Power Plants, IEC 964, International Electrochemical Commission, 1989.

18.3-2 Pulliam et al., A Methodology for Allocation of Nuclear Power Plant Control Functions to Human and Automated Control, NUREG/CR-3331, June 1983.

18.3-3 HSI System Description and HFE Process, MUAP-07007-P (Proprietary) and MUAP-07007-NP (Non-Proprietary), Revision 1, July 2007.

18.3-4 HSI Design Technical Report, MUAP-08XXX-P (Proprietary) and MUAP-08XXX-NP (Non-Proprietary), later.

18.4 Task Analysis

18.4.1 Objectives and Scope

The task analysis is based on the Japanese APWR design with additional analysis performed for differences in the US-APWR design. The objective of the task analysis is to identify the specific tasks that are needed for function accomplishment and the associated information, control, and task-support requirements.

Scope of the task analysis includes the following:

- Selected representative and important tasks from areas of the following:
  - Operations
  - Maintenance
  - Test
  - Inspection
  - Surveillance
- Full range of plant operating modes, including the following:
  - Startup
  - Normal operations
  - Abnormal and emergency operations
  - Transient conditions
  - Low-power and shutdown conditions
- HAs that have been found to affect plant risk by means of probabilistic risk assessment (PRA) importance and sensitivity analyses may also be considered risk-important. Internal and external initiating events and actions affecting the PRA Level I and II analyses are considered when identifying risk-important actions.
- Where critical functions are automated, the analyses consider all human tasks; including monitoring of the automated system and execution of backup actions if the system fails.
- The task analysis identifies information and control requirements to enable specification of detailed requirements for alarms, displays, data processing, and controls.

The task analysis also addresses issues such as the following:

- Operating personnel staffing
- Procedure development
- Operating personnel skill requirements
  - Job formation and training
  - Physical workload
  - Cognitive workload

18.4.2 Methodology

The detailed methodology for conducting the task analysis and integrating it into the HFE analyses is documented in this section and in Reference 18.4-1.

Task analyses begin on a gross or high level and involve the development of detailed narrative descriptions of what personnel have to do. The analyses define the nature of the input, process, and output needed by and from personnel.

Detailed narrative task descriptions address (as appropriate) the following topics:

- Information requirements
- Decisions making requirements
- Response requirements
- Communication requirements
- Workload
- Task support requirements
- Workplace factors
- Situational and performance shaping factors (PSFs)
- Hazard identification

The task analysis is iterative and becomes progressively more detailed over the design cycle. The task analysis is detailed enough to identify information and control requirements to enable specification of detailed requirements for alarms, displays, data processing, and controls for human task accomplishment. The task analysis addresses issues such as the following:

- The number of crew members
- Crew member skills
- Allocation of monitoring and control tasks for the following purposes:
  - Definition of a meaningful job scope
  - Management of crew member’s physical workload
  - Management of crew member’s cognitive workload

18.4.2.1 Description of the Methods Used to Analyze Tasks

The general task analysis methodology is described in Reference 18.4-1, Subsection 5.4.3. The operational sequence diagram (OSD) method is used to conduct functional-based task analysis. The goals, operators, methods, and selection (GOMS) method (Reference 18.4-2) was used to conduct cognitive skills task analysis.

18.4.2.2 General Task Analysis Methods

The OSD method is applied for analysis of US-APWR operations. OSD is used because it is applicable from the initial facility design phase to the final design phase. An OSD represents operator and computer tasks in graphical scheme sequentially and indicates actions, data transmitted or received, inspections, operations, decisions, and data storage. The information flow is shown in relation to both time and space. This method is used to develop and present the system reaction to specific inputs and display the interrelationship between operators and equipment. Detailed task analysis tools (e.g., task description method or functional flow diagram, Reference 18.4-3) are employed to supplement OSD, as needed.

The HEDs identified during the performance of the task analyses are documented, tracked, and dispositioned.

18.4.2.3 Detailed Cognitive Task Analysis Methods

In order to evaluate a crewmember’s cognitive workload, an interaction analysis between human and computer systems is necessary. GOMS is a method for the analysis of the cognitive skills involved in human-computer tasks. It is based upon an information-processing framework that assumes a number of different stages or types of memory and separate perpetual, motor, and cognitive processing times. Selected scenarios are analyzed using this method and detailed quantitative metrics are obtained. This information is used to develop the HSI design.

18.4.3 Results

The task analysis results are documented in the Technical Report (Reference 18.4-4). The task analysis results provide input to the design of HSIs, procedures, and personnel training programs.

18.4.4 Combined License Information

No additional information is required to be provided by a COL Applicant in connection with this section.

COL 18.4(1) Deleted

COL 18.4(2) Deleted

COL 18.4(3) Deleted

18.4.5 References

18.4-1 HSI System Description and HFE Process, MUAP-07007-P (Proprietary) and MUAP-07007-NP (Non-Proprietary), Revision 1, July 2007.

18.4-2 Card, S., Moran, T.P., and Newell, A, The Psychology of Human-Computer Interaction, Part II, Lawrence Erlbaum Associates, Hillsdale, NJ, 1983.

18.4-3 Burgy, D, Lempges, C., Miller, A., Schroeder, Van Cott, L.H., Paramore, B., Task Analysis of Nuclear Power Plant Control Room Crews, NUREG/CR-3371, Volumes 1 and 2, September 1983.

18.4-4 HSI Design Technical Report, MUAP-08XXX-P (Proprietary) and MUAP-08XXX-NP (Non-Proprietary), later.

18.5 Staffing and Qualifications

18.5.1 Objectives and Scope

The objective of the staffing and qualifications analysis is to determine the numbers and qualifications of personnel required for safe and efficient plant operation in a systematic manner that includes a thorough understanding of task requirements and applicable regulatory requirements. During the HFE design phase, staffing qualification analysis is focused primarily on personnel positions that are required for participation in the HFE design and V&V process as described in Section 18.1.

18.5.2 Methodology

The MHI staffing analysis for the US-APWR addresses applicable requirements of 10 CFR 50.54 (Reference 18.5-1) and NUREG-0800, Subsections 13.1.2 and 13.1.3 (Reference 18.5-2) that are necessary to ensure that personnel supporting the procedure, training, HSI development, and the V&V process are sufficient in number and qualifications to permit an adequate response to reference plant conditions. The detailed methodology for conducting the staffing and qualifications analysis and integrating it into the HFE analyses is documented in this section.

The staffing analysis determines the number and background of personnel for the full range of plant conditions and tasks including operational tasks (normal, abnormal, and emergency), plant maintenance, and plant surveillance and testing. The scope of personnel that are considered is identified in the HFE Program Management element (see NUREG-0711 (Reference 18.5-3), Subsection 2.4.1, Criterion 5), and is properly documented.

The plant personnel who are addressed by the HFE program include licensed control room operators (ROs and SRO) as defined in 10CFR55 (Reference 18.5-4), and the following categories of personnel defined in 10CFR50.120 (Reference 18.5-5):

- Non-licensed operators (Note 1)
- Shift supervisors
- Shift technical advisor
- I&C technicians (Note 1)
- Electrical maintenance personnel (Note 1)
- Mechanical maintenance personnel (Note 1)
- Radiological protection technicians (Note 1)
- Chemistry technicians (Note 1)

- Engineering support personnel (Note 1)

Note 1: Staffing analysis of personnel in these positions is limited to those performing the following activities: on-line testing and maintenance required by technical specifications; radiological protection activities supporting technical specifications, required maintenance, and emergency and abnormal response; and required chemical monitoring supporting technical specifications, and abnormal and emergency response.

In addition, any other plant personnel that perform tasks directly related to plant safety are addressed in the staffing analysis. Personnel meeting the qualifications (or documented equivalent) of Reference 18.5-6, Sections 4.4 and 4.5, are used to develop the HSI, training, and procedures, and participate in the V&V process.

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

The basis for staffing and qualifications requirement is modified to address these issues associated with the following HFE elements:

- OER
  - Operational problems and strengths that resulted from staffing levels in predecessor systems
  - Initial staffing goals and their bases, including staffing levels of predecessor systems and a description of significant similarities and differences between predecessor and current systems
  - Staffing considerations described in NRC Information Notice 95-48, "Results of Shift Staffing Study" (Reference 18.5-7)
  - 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" (Reference 18.5-8)
- Functional requirements analysis and function allocation
  - Mismatches between functions allocated to personnel and their qualifications
  - Changes to the roles of personnel due to plant system and HFE modifications
- Task analysis
  - Knowledge, skills, and abilities needed for personnel tasks addressed by the task analysis
  - Personnel response time and workload

- Personnel communication and coordination, including interactions between them for diagnosis, planning, and control activities, and interactions between personnel for administrative, communications, and reporting activities

- Job requirements that result from the sum of all tasks allocated to each individual, both inside and outside of the control room

- Decreases in the ability of personnel to coordinate their work due to plant and HFE modifications

- Availability of personnel considering other activities that may be ongoing and for which operators may take on responsibilities outside the control room (e.g., fire brigade)

- Actions identified in 10 CFR 50.47 (Reference 18.5-9), NUREG-0654 (Reference 18.5-10), and the procedures to meet an initial accident response in key functional areas, as identified in the emergency plan

- Staffing considerations described by the application of American National Standards Institute (ANSI)/American Nuclear Society (ANS) 58.8-1994, "Time Response Design Criteria for Safety-Related Operator Actions" (Reference 18.5-11)

• HRA

  - Effect of overall staffing levels on plant safety and reliability

  - Effect of overall staffing levels and crew coordination for risk-important HAs

  - Effect of overall staffing levels and the coordination of personnel on human errors associated with the use of advanced technology

• HSI Design

  - Staffing demands resulting from the locations and use (especially concurrent use) of controls and displays

  - Coordinated actions between individuals

  - Decreases in the availability or accessibility of information needed by personnel due to plant system and HFE modifications

  - Physical configuration of the control room and control consoles

  - Availability of plant information from individual workstations and group-view interfaces

• Procedure Development

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

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

18.5.3 Results

A staffing and qualification analysis is developed and documented in the staffing and qualifications analysis report. The staffing and personnel qualifications required for the US-APWR are demonstrated by the V&V process to be adequate for plant personnel who perform tasks that are directly related to plant safety. Changes to staffing levels or personnel used in the HFE development are documented and analyzed for their potential impact on HSIs. Those staffing and qualification program issues that negatively impact human performance are identified as HEDs and are tracked and dispositioned.

18.5.4 Combined License Information

No additional information is required to be provided by a COL Applicant In connection with this section.

COL 18.5(1) Deleted

COL 18.5(2) Deleted

18.5.5 References

18.5-1 Conditions of Licenses, NRC Regulations Title 10, Code of Federal Regulations, Part 50.54.

18.5-2 U.S. Nuclear Regulatory Commission, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, NUREG-0800, Subsections 13.1.2 – 13.1.3 “Operating Organization”, March 2007.

18.5-3 U.S. Nuclear Regulatory Commission, Human Factors Engineering Program Review Model, NUREG-0711, Revision 2, February 2004.

18.5-4 Operators’ Licenses, NRC Regulations Title 10, Code of Federal Regulations, Part 55.

18.5-5 Training and Qualification of Nuclear Power Plant Personnel, NRC Regulations Title 10, Code of Federal Regulations, Part 50.120.

18.5-6 Selection, Qualification, and Training of Personnel for Nuclear Power Plants, ANSI/ANS 3.1, 1993.

18.5-7 Results of Shift Staffing Study, Information Notice 95-48, 1995.

18.5-8 Crediting of Operator Actions in Place of Automatic Actions and Modifications of Operator Actions, Including Response Times, Information Notice 97-78, 1997.

18.5-9 Emergency Plans, NRC Regulations Title 10, Code of Federal Regulations, Part 50.47.

18.5-10 U.S. Nuclear Regulatory Commission, Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants, NUREG-0654, October 1980.

18.5-11 Time Response Design Criteria for Safety-Related Operator Actions, ANSI/ANS 58.8, 1994.

18.6 Human Reliability Analysis

18.6.1 Objectives and Scope

The objective of this section is to document that HRA/PRA results are thoroughly incorporated into the HFE design analysis and that the HFE design process interacts iteratively with the HRA/PRA. The proper interaction of HFE design and HRA/PRA most effectively contributes to minimizing personnel errors, allowing human error detection, and providing human error recovery capability. The human performance assumptions, based on the HFE design influence on the HRA/PRA, are confirmed as part of the task analysis and the control room validation.

The scope of the HRA/PRA incorporation into the HFE design effort encompasses risk-important HAs. The iterative nature of the interaction of HFE design and the HRA/PRA continues as the design progresses. The primary influence of the HRA/PRA on the HFE design manifests itself in changes to the task analysis primarily by developing more accurate estimates of workload and task completion times.

18.6.2 Methodology

The methodology for integrating the HRA/PRA into the HFE analyses is described below.

Incorporating HRA/PRA results into the HSI design process involves identifying risk-important HAs, addressing the HAs in the HFE analysis and design process, and validating HFE design changes. The guidelines for incorporating the HRA/PRA into the HFE analysis, as contained in Reference 18.6-1, are used to achieve the integration.

- Risk-important HAs are identified from the PRA/HRA and used as input to the HFE design effort. These actions are extracted from the Level 1 (core damage) PRA and Level 2 (release from containment) PRA including both internal and external events. They are developed using several importance measures and HRA sensitivity analyses to provide reasonable assurance that an important action is not overlooked because of the selection of the measure or the use of a particular assumption in the analysis. The HRA methodology is described in Subsection 19.1.4.1.1, “Description of the Level 1 Probabilistic Risk Assessment for Operations at Power” and Subsection 19.1.6.1, “Description of Low-Power and Shutdown Operations” The categorization of the risk-importance of HAs is described in Subsections 19.1.4.1.1 and 19.1.6.1.

- Risk-important HAs and their associated tasks and scenarios are specifically addressed during function allocation analyses, task analyses, HSI design, procedure development, and training development. Proper consideration of HAs helps verify that these tasks are well supported by the design and within acceptable human performance capabilities (e.g. within time and workload requirements).

- The HFE design team characterizes risk-important human-system interactions by identifying the performance shaping factors (PSF) as described in Reference

18.6-2, Subsection 4.5.2. The team then applies HFE guidelines to the HSI to optimize the PSF, thereby enhancing the overall human success probability.

- HRA assumptions such as decision-making and diagnosis strategies for dominant sequences are validated by walkthrough analyses with personnel with operational experience using a plant-specific control room mockup or simulator. Reviews are conducted before the final quantification stage of the PRA as part of the V&V process.

18.6.3 Results

The Technical Report (Reference 18.6-3) documents the following:

- The risk significant HAs
- Optimization of the HSI design to minimize human error probabilities
- Consistency between the HSI design and the PRA/HRA assumptions
- Traceability of risk significant tasks into each element of the HFE program, including task analysis, HSI design, procedures and training, V&V, and human performance monitoring

18.6.4 Combined License Information

No additional information is required to be provided by a COL Applicant in connection with this section.

COL 18.6(1) *Deleted*

COL 18.6(2) *Deleted*

18.6.5 References

18.6-1 Higgins, J.C. and O'Hara J.M., Proposed Approach for Reviewing Changes to Risk-Important Human Actions, NUREG/CR-6689, October 2000.

18.6-2 IEEE Guide for Incorporating Human Action Reliability Analysis for Nuclear Power Generating Stations, IEEE Std 1082-1997, Institute of Electrical and Electronics Engineers, NY, September 1997.

18.6-3 HSI Design Technical Report, MUAP-08XXX-P (Proprietary) and MUAP-08XXX-NP (Non-Proprietary), later.

18.7 Human-System Interface Design

18.7.1 Objectives and Scope

This section documents the HSI design process and the basic design including the translation of function and task requirements into the design of alarms, displays, controls, and other aspects of the HSI through the systematic application of HFE principles and criteria. The development of HSI design requirements are also described as well as the process of how HSI designs are identified and refined. Design requirements are developed and documented as described below.

18.7.2 Methodology

Reference 18.7-1 provides a detailed description of the design of the US-APWR control room, control consoles, and user interfaces, and the methodology used to develop that design. The Japanese and international standards, Japanese nuclear power plant operating experience, and NRC-directed operating considerations are applied to the APWR HFE design and are discussed in Reference 18.7-1, Appendices A and B and its supporting references. The Japanese APWR HFE design underwent a V&V process conducted in accordance with Japanese requirements. This control room and HSI configuration are the basis for the US-APWR design. However, the US-APWR control room configurations and HSIs are to be demonstrated to comply with all NRC regulations as stated in the Abstract of Reference 18.7-1, by full implementation of the analyses described in Sections 18.2, 18.3, 18.4, 18.5, and 18.6 above; the verification of the HFE design is evaluated with respect to the guidelines in Reference 18.7-2 as described in this Section; and a full V&V as described in Section 18.10. The design deficiencies are identified and dispositioned. The detailed HSI design process is documented as follows.

18.7.2.1 HSI Design Inputs

The Japanese APWR HSI design is the initial design input for the US-APWR design, as discussed above. The following sources of the US-APWR information, developed as described in Sections 18.2 through 18.6 provide input to the US-APWR HSI design process:

- Analysis of Personnel Task Requirements – The analyses performed in earlier stages of the design process are used to identify requirements for the HSIs. These analyses include the following:

  - Operational experience review – Lessons learned from other complex human-machine systems, especially predecessor designs and designs involving similar HSI technology are used as an input to HSI design. The OER is described in Section 18.2.

  - Functional requirement analysis and function allocation – The HSIs support the operator’s role in the plant (e.g., appropriate levels of automation and manual control). The FRA and FA are described in Section 18.3.

- Task analysis – The set of requirements to support the role of personnel is provided by task analysis. The task analysis is described in Section 18.4. The task analysis identifies the following:
    - Tasks that are necessary to control the plant in a range of operating conditions for normal through accident conditions
    - Detailed information and control requirements (e.g., requirements for display range, precision, accuracy, and units of measurement)
    - Task support requirements (e.g., special lighting and ventilation requirements)
- Risk-important HAs and their associated PSFs, as identified through HRA, are given special attention in the HSI design process. The HRA integration into the HSI design process is described in Section 18.6.
- Staffing/qualifications and job analyses – The results of staffing/qualifications analyses provide input for the layout of the overall control room and the allocation of controls and displays to individual consoles, panels, and workstations. This establishes the basis for the minimum and maximum number of personnel to be accommodated and requirements for coordinating activities between personnel. The staffing/qualifications and job analyses are described in Section 18.5.

- System Requirements – Constraints imposed by the overall I&C system, such as redundancy, equipment qualification, and coping with common mode failures are significant inputs for the HSI design and are considered throughout the HSI design process
- Regulatory and Other Requirements – Applicable regulatory requirements and industry standards, including those identified in Reference 18.7-1 Section 3.0 “Applicable Codes, Standards, and Regulatory Guidance,” are inputs to the HSI design process.

18.7.2.2 Concept of Operations

The concept of operations for the US-APWR is as described in Reference 18.7-1, Section 4.1, and includes:

- Crew composition (see Reference18.7-1 Subsection 4.1.f)
- Roles and responsibilities of individual crewmembers (see Reference 18.7-1, Subsection 4.1.g)
- Personnel interaction with plant automation (see Reference 18.7-1, Subsections 4.1.a, 4.1.b, 4.1.e)

- Use of control room resources by crewmembers (see Reference 18.7-1, Sections 4.1.c and 4.1.d)
- Methods used to ensure good coordination of crewmember activities, including non-licensed operators, technicians, and maintenance personnel. These coordination tools/methods include:
  - Large display panel (LDP) (see Reference 18.7-1, Section 4.9)
  - LCSs (see Reference 18.7-1, Subsection 4.2.5)
  - Tagging (see Reference 18.7-1, Section 4.5)

In addition, distribution of plant data via the unit bus and the plant station bus is described in Section 7.9, voice communications systems for the US-APWR are described in Subsection 9.5.2, and video communications systems, such as industrial television (ITV), for the US-APWR are described in Reference 18.7-1 Subsection 4.3.1.

18.7.2.3 Functional Requirements Specification

Reference 18.7-3 identifies the key principles of functional requirements specification in Chapter 4, "Functional Design Specification," with additional analytical detail provided in Appendix A, "Design Guide for Control Rooms," Section A.4. These basic functional requirements for all HSI resources are reflected in the HSI design described in the Topical Report (Reference 18.7-1). During the detailed design process additional functional requirements for HSIs are added reflecting the output from the task analysis, including alarm, information and control content for specific displays.

18.7.2.4 HSI Concept Design

The US-APWR HSI design is a direct evolution of the predecessor standard Japanese PWR HSI design, as described in Reference 18.7-1 and shown in Reference 18.7-1, Appendix B, Figure B-2. The development of the standard Japanese PWR from concept phase through final design is described in Reference 18.7-1, Appendix A. Figure 7.1-7 in Section 7.1 shows the conceptual MCR layout of the US-APWR. The final MCR layout, resulting from all phases of the HSI design process, is described in the HSI Design Technical Report (Reference 18.7-5).

- The primary changes from the standard Japanese PWR HSI design that are reflected in the US-APWR HSI design are described in Sections 18.2 and 18.3. These include:
  - Automating channel checks
  - Automatic isolation of a failed SG (the function is to be implemented inside protection and safety monitoring system (PSMS))

  - Elimination of manual actions required to establish ECCS recirculation (this also a change from conventional US PWRs)

  - Arrangement of the main control room operator consoles to accommodate the control actions and monitoring by one or two reactor operators (the Japanese APWR design accommodates control by one operator)

  - Conversion from two-train to four-train design for safety systems

  - HSI modified to accommodate the US-APWR specific plant mechanical and electrical systems

  - Japanese-to-English language conversion

  - Metric-to-English units conversion

  - Ergonomics changes to accommodate the expected range of US operating personnel, in accordance with Reference 18.7-2

  - Console designs to accommodate modern HSI technology (e.g., flat panel displays versus rear projection displays)

  - Control devices to incorporate US operation personnel preferences (e.g., mouse, touch screens and other pointing devices)

- The functional requirement specification for the Japanese APWR HSI design serves as the initial source of input to the HSI design effort. The US-APWR HSI design is a direct evolution from the predecessor standard Japanese PWR. The following criteria in this section were considered during the development of the standard Japanese PWR and the HSI design.

  - Alternative approaches for addressing HSI functional requirements were considered. A survey of the state-of-the-art in HSI technologies was conducted to:

    - Support the development of concept designs that incorporate advanced HSI technologies

    - Provide assurance that proposed designs are technically feasible

    - Support the identification of human performance concerns and tradeoffs associated with various HSI technologies

  - Alternative approaches for addressing HSI functional requirements were considered. Evaluation methods included operating experience and literature analyses, and engineering evaluations.

- Alternative concept designs were evaluated so that one can be selected for further development. The evaluation provides reasonable assurance that the selection process is based on a thorough review of design characteristics and a systematic application of selection criteria. Tradeoff analyses, based on the selection criteria, provide a rational basis for the selection of concept designs.

- HSI design performance requirements were identified for components of the selected HSI concept design. These requirements were based on the functional requirement specifications and were refined to reflect HSI technology considerations identified in the survey of the state of the art in HSI technologies and human performance considerations identified in human performance research and evaluations.

- Human performance issues identified from operating experience with the predecessor design are resolved.

18.7.2.5 HSI Detailed Design and Integration

The HSI detailed design and integration for the US-APWR is based on the standard Japanese APWR HSI design. The standard Japanese APWR HSI design was developed based on generic HFE design guidance (style guide). The style guide is described in the Topical Report (Reference 18.7-1), including the scope, contents, and procedures. The style guide provides the HFE guidelines utilized in the design of the HSI features, layout, and environment. The style guide was developed in accordance with Reference 18.7-2, which was the primary source of design guidance; guidelines from other sources were incorporated and identified by reference. Key aspects of the style guide are as follows:

- The content of the style guide is derived from (1) the application of generic HFE guidance to the specific application, and (2) the development of situation-specific guidelines based upon design-related analyses and experience. Guidelines that are not derived from generic HFE guidelines may be justified based on an analysis of recent literature, analysis of current industry practices and operational experience, tradeoff studies and analyses, and the results of design engineering experiments and evaluations. The guidance is tailored to reflect design decisions made to address specific goals and needs of the HSI design.

- The topics in the style guide address the scope of HSIs included in the design and address the form, function, and operation of the HSIs as well as environmental characteristics relevant to human performance.

- The individual guidelines are expressed in concrete, easily observable terms. In general, generic HFE guidelines are used in their abstract form. Such generic guidance is translated into more specific design guidelines that can, as much as possible, provide unambiguous guidance to designers and evaluators. The design guidelines are detailed enough to permit their use by design personnel to achieve a consistent and verifiable design that meets the HFE guideline.

- The style guide provides procedures for determining where and how HFE guidance is used in the overall design process. The style guide is written so it can be readily understood by designers. The style guide supports the interpretation and comprehension of design guidance by supplementing text with graphical examples, figures, and tables.

- The guidance is maintained in a form that is readily accessible and usable by designers and that facilitates modification when the contents require updating as the design matures. Each guideline included in the guidance documentation includes a reference to the source upon which it is based (as applied in Reference 18.7-2).

The standard Japanese APWR HSI style guide is updated to address HSI modifications for the US-APWR, as described in the section above. The style guide specifically addresses consistency in design across the HSIs.

The HSI detailed design and integration described in the Topical Report (Reference 18.7-1) is applicable to the US-APWR. The Topical Report describes:

- How the design supports personnel in their primary role of monitoring and controlling the plant, while minimizing the demands associated with interface management. The operational visual display units (VDUs) provide access to all information and controls, both Safety and Non safety. The LDP provides a continuous display to support situation awareness and crew interaction for all modes of operation.

- How the design addresses the safety parameter display system (SPDS) parameters referenced in 10 CFR 50.34(f)(2)(iv) (Reference 18.7-4). The LDP provides continuous display for the status of all critical safety functions and the plant systems used to control those safety functions. The electronic procedure system supports execution of the functional recovery EOPs.

- How the design minimizes the probability of error in the performance of risk-important HAs and provides the opportunity to detect errors, if they should occur. There are two actions required, if the operator’s action may cause a spurious actuation of a system that may cause a transient. In addition, operational VDU displays are designed to support credited manual operator actions for event-based mitigation.

- The basis for allocation of HSI functions to either the main control room or LCS. All control functions are accessible in the main control room and no LCS controls are credited for normal operation or accident condition operator response. The basis for the control room layout, and the organization of HSIs within consoles, panels, and workstations – the MCR is designed to support the range of crew tasks and staffing (MCR layout is discussed in Reference 18.7-1 Subsection 4.3.1); operational VDUs which are used during all normal and emergency modes of operation are centrally located.

- How the control room supports a range of anticipated staffing situations – the design accommodates minimum and nominal staffing, as described in Section 18.5; in addition, sufficient space is available to accommodate shift turnover transitions.

- How the HSI characteristics mitigate excessive fatigue – lighting, as described in Subsection 9.5.3, and ergonomics, as described in Reference 18.7-1, Section 4.3, Layout Design.

- How the HSI characteristics support human performance under a full range of environmental conditions – highly controlled environment without a significant fluctuation of environmental conditions, including emergency lighting, Subsection 9.5.3; ventilation, Section 9.4; and control room habitability, as discussed in Section 6.4.

- The means by which inspection, maintenance, tests, and repair of HSIs is accomplished without interfering with other control room tasks – Reference 18.7-1, Section 4.11 “Response to HSI Equipment Failures” discusses response to HSI equipment failures without impacting plant control functions.

Overall HFE issues associated with the central alarm station (CAS) and the secondary alarm station (SAS) are discussed in Section 13.6, Security. The HSI Detailed Design and Integration process encompasses the HSI design aspects of the CAS and SAS.

18.7.2.6 HSI Tests and Evaluations

The control room HSI development of the Japanese APWR, as described in Reference 18.7-1 Appendix A, included trade-off evaluations and performance-based tests. The evaluations and testing associated with this HSI development is described in a series of historical project summary reports. This work was conducted in conjunction with Japanese nuclear utilities that provided the nuclear plant operating staff that supported the testing efforts. The performance of the operating staff was evaluated as described in Reference 18.7-1 Appendix B and the associated references. Additional tests and evaluations for the US-APWR HSI design are described in Section 18.10.

18.7.3 Results

The US-APWR HSI design results and description are documented in the HSI Design Technical Report (Reference 18.7-5).

18.7.3.1 Overview of HSI Design and Its Key Features

The US-APWR HSI Design Technical Report (Reference 18-7-5) describes the overall design concept and its rationale. This description includes the MCR, remote shutdown console (RSC), TSC, and LCSs that are important to safety. Key features of the design, such as information display, “soft” controls, CBPs, alarm processing, and control room layout, are described. The HSI Design Technical Report (Reference 18-7-5) includes the following:

- The detailed HSI description, including its form, function and performance characteristics
- The basis for the HSI requirements and design characteristics with respect to operating experience and literature analyses, tradeoff studies, engineering evaluations and experiments, and benchmark evaluations
- The basis of any design changes from the Japanese APWR HSI design
- The outcomes of tests and evaluations performed in support of HSI design

18.7.3.2 Safety Aspects of the HSI

The US-APWR HSI Design Technical Report (Reference 18-7-5) also describes the US-APWR specific implementation of the following safety aspects of the HSI, which are coordinated with the I&C design:

- Safety function monitoring
- Periodic testing of protection system actuation functions
- Bypassed and inoperable status indication for plant safety systems
- Manual initiation of protective actions
- Instrumentation required to assess plant and environmental conditions during and following an accident
- Setpoints for safety-related instrumentation
- HSIs for the emergency response facilities (TSC and EOF, where TSC and EOF utilize common technologies)

In addition, the HSI Design Technical Report (Reference 18.7-5) describes the minimum Inventory of HSIs for the US-APWR, which includes:

- Fixed position continuously visible HSI provided by:
  - The fixed area of the LDP (Table 18.7-1) - Section 4.9 “Large Display Panel” of Reference 18.7-1 provides the design basis and description of all LDP indications and alarms, which includes:
    - Bypassed and inoperable status indication (BISI) parameters
    - Type A and B post monitoring (PAM) variables (Section 7.5, Table 7.5-3)
    - Safety parameter displays including status of critical safety functions and performance of credited safety systems and preferred non safety systems

        · Prompting alarms for credited manual operator actions and risk important HAs identified in the HRA

    - PAM displays for Type A and B variables on the safety VDUs (Subsection 7.5.1.1)

    - Conventional switches on the MCR operator console for system level actuation of safety functions such as reactor trip, engineering safety features actuation system (ESFAS) actuation, etc. (Tables 7.2-6 and 7.3-5)

- Class 1E HSI for control of all safety-related components and monitoring of all safety-related plant instrumentation is provided on the safety VDUs, located on the MCR operator console and the remote shutdown console (Section 7.1).

- Minimum inventory for degraded HSI conditions - Section 4.11 “Response to HSI Equipment Failures” of Reference 18.7-1 provides the design basis and description of redundant and diverse HSI which supports the following degraded operating conditions:

    - Degraded operations based on loss of non safety HSI. The plant is maintained in a stable condition through continued operation of normal automatic control systems and monitoring and controlling of critical safety functions through safety VDUs.

    - Degraded operations based on loss of safety and non safety HSI due to common cause failure. HSI for accident mitigation and achieving safe shutdown is provided by the DHP (Subsection 7.8.3).

    - Degraded operations based on evacuation of the MCR. Safe shutdown is achieved through HSI at the RSC (Subsection 7.4.1.5).

    - Degraded operations based on single HSI failures. All information and controls are available to continue normal plant operation, manage accidents and achieve safe shutdown through alternate HSI devices (Reference 18.7-1, Subsection 4.11.2).

18.7.3.3 HSI Change Process

The HFE Design Report (Reference 18-7-5) documents the process for the following HSI changes:

- Topical Report (Reference 18.7-1 Subsection 4.5.2 “Operation Method”) describes HSI for setpoints that are expected to be changed by operators during normal operations.

- HSIs designs that are modified and updated on a permanent basis (see Section 18.11).

- Temporary setpoint modifications. These changes are made through changes in the PSMS or plant control and monitoring system (PCMS) software. The software management life cycle process is described in Subsection 7.1.3.17.

- Configuration of operator-managed trend displays and operator-managed alarms. Operators can configure new trend displays and new alarms that are not pre-configured in the HSI design. The configuration tools ensure consistency with the HSI style guide. This operator configured HSI does not change any pre-configured HSI. Operator-managed trend displays and operator-managed alarms are controlled through administrative procedures.

- Data entry into the PCMS for maintenance related work order management (Reference 18.7-1 Subsection 4.5.3). This function is administratively controlled.

18.7.4 Combined License Information

No additional information is required to be provided by a COL Applicant in connection with this section.

COL 18.7(1) Deleted

18.7.5 References

18.7-1 HSI System Description and HFE Process, MUAP-07007-P (Proprietary) and MUAP-07007-NP (Non-Proprietary), Revision 1, July 2007.

18.7-2 U.S. Nuclear Regulatory Commission, Human-System Interface Design Review Guidelines, NUREG-0700, Revision 2, May 2002.

18.7-3 Design for Control Rooms of Nuclear Power Plants, IEC 964, International Electrochemical Commission, 1989.

18.7-4 Post-TMI Requirements, NRC Regulations Title 10, Code of Federal Regulations, Part 50.34.

18.7-5 HSI Design Technical Report, MUAP-08XXX-P (Proprietary) and MUAP-08XXX-NP (Non-Proprietary), later.

Table 18.7-1 Parameters on LDP (Sheet 1 of 9)

	Plant Power	Cause of Reactor Trip	Plant Trip	ESFAS Actuation	PAM	SDCV Alarm (Note 1)	OK Monitor (Note 2)	SPDS
Reactor Thermal Power	X							
Turbine Power	X							
Generator Power	X							
Nuclear Instrumentation System (NIS) Power	X	X						
Pressurizer Pressure	X	X				X		
Pressurizer Water Level	X	X			X	X		X
Pressurizer Reference Water Level	X							
RCS Average Temperature	X	X						
RCS Reference Temperature	X	X						
RCS Delta-Temperature	X	X						
RCS Hot Leg Temperature (Wide Range)					X			X
RCS Cold Leg Temperature (Wide Range)					X			X
RCS Subcooling (Loop)					X			X
RCS Subcooling (TC)					X			X
Core Outlet Temperature					X			X
RCS Pressure					X	X		X
Power Range Neutron Flux	X	X						

Table 18.7-1 Parameters on LDP (Sheet 2 of 9)

	Plant Power	Cause of Reactor Trip	Plant Trip	ESFAS Actuation	PAM	SDCV Alarm (Note 1)	OK Monitor (Note 2)	SPDS
Intermediate Range Neutron Flux	X	X	X	X	X			X
Source Range Neutron Flux	X	X	X	X	X	X		X
Intermediate Range Neutron Flux Change Rate		X	X	X				X
Source Range Neutron Flux Change Rate		X	X	X				X
SG Water Level (Narrow Range)	X	X			X	X		X
SG Water Level (Wide Range)					X			X
SG Reference Water Level	X	X						
Main Steam Line Pressure	X	X			X	X		
Main Steam Line Flow	X	X						
Main Feed Water Flow	X	X				X		X
Main Steam Tie Line Pressure	X	X						
Main Feed Water Head Pressure	X	X						
Turbine First Stage Pressure	X	X						
Charging Water Flow	X	X						
Letdown Water Flow	X	X						
Boric Acid Tank Water Level								
Component Cooling Water Surge Tank Water Level								

Table 18.7-1 Parameters on LDP (Sheet 3 of 9)

	Plant Power	Cause of Reactor Trip	Plant Trip	ESFAS Actuation	PAM	SDCV Alarm (Note 1)	OK Monitor (Note 2)	SPDS
Service Water Supply Line Pressure								
Containment Vessel (C/V) Pressure					X	X		X
C/V Temperature								X
C/V Annulus Pressure								
Class 1E Electrical Room Pressure								
Reactor Vessel Water Level					X			
Safety Injection Water Flow								
Residual Heat Removal (RHR) Flow								
Emergency Feed Water (EFW) Flow					X			X
C/V Spray Cooler Outlet Flow								X
Spent Fuel Pit Water Level								
Refueling Water Storage Pit (RWSP) Water Level					X			
EFW Pit Water Level					X	X		
C/V Sump Water Level						X		
C/V High Range Radiation Monitor								
C/V Dust Radiation Monitor						X		
C/V Gas Radiation Monitor						X		

Table 18.7-1 Parameters on LDP (Sheet 4 of 9)

	Plant Power	Cause of Reactor Trip	Plant Trip	ESFAS Actuation	PAM	SDCV Alarm (Note 1)	OK Monitor (Note 2)	SPDS
Condenser Ejection Gas Radiation Monitor						X		
SG Blow Down Radiation Monitor						X		
Main Steam Radiation Monitor						X		
N-16 Main Steam Radiation Monitor						X		
Exhaust Duct Gas Radiation Monitor						X		
Control Room Emergency HVAC System Status								
Emergency Power Generator				X				
Reactor Trip Breaker Status		X	X	X			X	X
Control Rod Position	X	X	X			X	X	X
Pressurizer Depressurization Valve	X	X						
Pressurizer Depressurization Valve Shutdown Valve	X	X						
Pressurizer Spray Valve	X	X						
Pressurizer Back Up Heater	X	X						
Pressurizer Control Heater	X	X						
MFW Control Valve	X	X		X			X	
MFW Bypass Control Valve	X	X		X			X	
SG Makeup Water Line Valve		X					X	

Table 18.7-1 Parameters on LDP (Sheet 5 of 9)

	Plant Power	Cause of Reactor Trip	Plant Trip	ESFAS Actuation	PAM	SDCV Alarm (Note 1)	OK Monitor (Note 2)	SPDS
MFW Isolation Valve	X	X		X			X	
EFW Isolation Valve				X			X	
Turbine Bypass Valve	X	X						
Main Steam Depressurization Valve	X	X						
Main Steam Relief Valve Isolation Valve	X	X						
Main Steam Isolation Valve	X	X		X			X	
Reactor Coolant Pump	X	X						
Charging Pump	X	X						
Component Cooling Water Pump		X		X			X	
Service Water Pump		X		X			X	
Safety Injection Pump				X			X	
C/V Spray/RHR Pump				X			X	
Emergency Feedwater Pump				X			X	
Instrument Air Compressor				X			X	
C/V Recirculation Fan				X			X	
Bearing Cooling Water Pump		X						
Main Turbine Stop Valve	X	X	X					

Table 18.7-1 Parameters on LDP (Sheet 6 of 9)

	Plant Power	Cause of Reactor Trip	Plant Trip	ESFAS Actuation	PAM	SDCV Alarm (Note 1)	OK Monitor (Note 2)	SPDS
Main Turbine Control Valve	X	X	X					
Reheat Stop Valve	X	X	X					
Interceptor Valve	X	X	X					
Turbine Rotation Rate	X	X						
Deaerator Pressure	X	X						
Deaerator Tank Water Level	X	X						
Condenser Vacuum Rate	X	X						
Condensate Pump	X	X						
Condensate Booster Pump	X	X						
Circulating Water Pump	X	X						
Power Factor	X	X						
Generator Frequency	X	X						
Generator Voltage	X	X						
Generator Current	X	X						
Turbine Shaft Vibration	X	X						
Feed Water Pump	X	X						
Feed Water Booster Pump	X	X						
Transmission Voltage	X	X		X				

Table 18.7-1 Parameters on LDP (Sheet 7 of 9)

	Plant Power	Cause of Reactor Trip	Plant Trip	ESFAS Actuation	PAM	SDCV Alarm (Note 1)	OK Monitor (Note 2)	SPDS
Class 1E 6.9kV Bus Voltage	X	X		X				
Non Class 1E 6.9kV Bus Voltage	X	X		X				
Main Transformer Circuit Breaker	X	X	X	X				
Generator Load Break Switch	X	X	X				X	
Generator Field Circuit Breaker	X	X	X				X	
Reserve Auxiliary Transformer Circuit Breaker	X			X			X	
Class 1E Emergency Power Generator Incoming Breaker	X	X		X			X	
Unit Auxiliary Transformer Incoming Breaker		X					X	
Class 1E 6.9kV Bus Power Receive Circuit Breaker	X			X				
Non Class 1E 6.9kV Bus Power Receive Circuit Breaker	X			X				
Switchyard Circuit Breaker		X						
Class 1E Direct Current Bus Voltage								
Reactor Trip Status			X				X	
Turbine Trip Status			X				X	
Generator Trip Status			X				X	
ECCS Status (ECCS Line-Up Valves)				X			X	
ECCS Sequence Components				X			X	

Table 18.7-1 Parameters on LDP (Sheet 8 of 9)

	Plant Power	Cause of Reactor Trip	Plant Trip	ESFAS Actuation	PAM	SDCV Alarm (Note 1)	OK Monitor (Note 2)	SPDS
LOOP Sequence Components				X			X	
C/V Spray Sequence Components				X			X	
Main Control Room Isolation Sequence Components				X			X	
C/V Isolation Phase A (T Signal) Actuating Valves				X	X		X	X
C/V Spray Signal Actuating Valves				X			X	
C/V Isolation Phase B (P Signal) Actuating Valves				X	X		X	X
C/V Isolation Phase A (T Signal) & Emergency Bus Under Voltage Signal Actuating Valves				X			X	
Safety Injection Signal & Emergency Bus Under Voltage Signal Actuating Valves				X			X	
C/V Purge Isolation Signal Actuating Valves				X			X	
Main Control Room Ventilation Isolation Signal Actuating Valves				X			X	X
Automatic Activation Block				X				
Main Steam Bypass Start Up Valve				X			X	
EFW Pump Outlet Flow Control Valve			X				X	
EFWP Drive Steam Inlet Valve			X				X	

Table 18.7-1 Parameters on LDP (Sheet 9 of 9)

	Plant Power	Cause of Reactor Trip	Plant Trip	ESFAS Actuation	PAM	SDCV Alarm (Note 1)	OK Monitor (Note 2)	SPDS
SG Sampling Line C/V Outside Isolation Valve				X			X	
SG Blow Down C/V Outside Isolation Valve				X			X	
SG Blow Down Stop Valve				X			X	
Safety Interlock Bypass (BISI Component level)							X	

Note 1: SDCV: specially dedicated continuously visible

Note 2: Prior to safety system actuation, the OK Monitors indicate operability status (i.e., BISI). After safety system actuation, OK Monitors indicate actuation status.

18.8 Procedure Development

18.8.1 Objectives and Scope

The objective of the procedure development program is to produce procedures that support and guide human interactions with plant systems and control plant-related events and activities. HFE principles and criteria are applied along with all other design requirements to develop procedures that are technically accurate, comprehensive, explicit, easy to use, and validated. The scope of the procedures program for the US-APWR is described in Chapter 13 (Section 13.5). Procedures for safety-related operations and maintenance activities are developed in accordance with the HFE program described in this section.

18.8.2 Methodology

The US-APWR Procedures program includes the development of computer based procedures with corresponding backup paper procedures, and stand-alone paper procedures for which there are no computer based procedures (eg. maintenance procedures).The US-APWR Procedures program addresses applicable requirements of NUREG-0800, Section 13.5 (Reference 18.8-1) that is necessary to ensure that procedures accurately reflect the US-APWR plant conditions. The detailed procedure development process is discussed below. The CBP generated by this program are an integral part of the HSI V&V process.

Reference 18.8-2 Section 4.8 provides a detailed description of the US-APWR CBP design, including user interfaces and the methodology used to develop that design. The US-APWR CBP design is based on the CBP for the Japanese APWR. The Japanese and international standards, Japanese nuclear power plant operating experience, and NRC-directed operating considerations have been applied to the Japanese APWR CBP design and are discussed in Reference 18.8-2.

The US-APWR CBP and paper procedures are based on the procedures from the Japanese standard 4-loop PWR. The changes to these procedures reflect the functional requirements analysis and function allocation, which are conducted based on the following:

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

The Japanese APWR CBP design and procedures for the Japanese standard 4-loop PWR underwent a V&V process conducted in accordance with Japanese requirements. This CBP design and procedures are the basis for the US-APWR. However, the US-APWR CBP design and procedures are demonstrated to comply with NRC regulations, as stated in the following sections.

18.8.2.1 Procedure Development Bases

The basis for procedure development includes the following:

- 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 the EOPs, including those events in the design bases
- Generic technical guidelines for EOPs, system operations procedures (including startup, power, and shutdown operations), test and maintenance procedures

The process of the procedure development is described in Reference 18.1-1 Subsection 5.8.2.

18.8.2.2 Procedure Writer's Guide Content Development

A US-APWR procedures writer's guide has been developed to establish the process for developing technical procedures that are complete, accurate, consistent, and easy to understand and follow. The procedures writer's guide contains objective criteria so that procedures developed in accordance with it are consistent in organization, style, and content. The procedures writer's guide is used for all procedures within the scope of this element. It provides instructions for procedure content and format, including the writing of action steps and the specification of acceptable acronym lists and acceptable terms to be used.

The US-APWR procedures writer's guide is based on the procedures writer's guide for the standard Japanese PWR. Changes accommodate conformance to U.S. regulatory requirements discussed in subsections below and cross-cultural issues such as Japanese-to-English language conversion and Metric-to-English units conversion.

18.8.2.3 Procedure Logic and Content Development

The writing style, format and organization guidance contained in Reference 18.8-3, Attachment A, is incorporated into the US-APWR procedures writer's guide, for operating procedures. The US-APWR procedures writer's guide ensures that the content of the operating procedures incorporates the following elements:

- Title and identifying information (such as number, revision, and date)
- Statement of applicability and purpose

- Prerequisites
- Precautions (including warnings, cautions, and notes)
- Important HAs
- Limitations and actions
- Acceptance criteria
- Check-off lists
- Reference material

The EOPs are developed incorporating the guidance contained in References 18.8-4 and 18.8-5. Generic technical guidelines and EOPs are symptom-based with clearly specified entry and exit conditions. Transitions between and within the normal operating, alarm response, and abnormal operating procedures and the EOPs are appropriately laid out, well defined, and easy to follow.

All procedures are verified and validated, and include the following:

- Technical reviews to verify that procedures are correct and can be carried out.
- Final validation to be performed in a simulation of the integrated system as part of the V&V activities described in the human factors V&V element (see Section 18.10).
- Verification of adequate content, format, and integration is performed when procedures are modified. The procedures also are assessed through validation if a modification substantially changes personnel tasks that are significant to plant safety. The validation verifies that the procedures correctly reflect the characteristics of the US-APWR plant, and can be carried out effectively to restore the plant to a safe condition.

18.8.2.4 Computer-based Procedure Program Development

For the standard Japanese APWR HSI design, an analysis was conducted to determine the impact of providing CBPs and to specify where such an approach improved procedure utilization and reduced operating crew errors related to procedure use. The performance of operating crews utilizing CBPs and paper procedures was evaluated, as described in Reference 18.8-2 Appendix B and the associated references. This evaluation included operator performance during degraded HSI conditions, including the loss of CBPs. The justifiable use of CBPs over paper procedures, and in conjunction with paper procedures, was documented. Feedback from operating crews was incorporated into the CBP and paper procedure designs. Since the US-APWR CBP design and paper procedures are based on the Japanese CBP design and paper procedures, with changes primarily for plant process systems, this evaluation is applicable to the US-APWR.

As in the Japanese APWR HSI design, the US-APWR HSI design includes backup paper procedures to accommodate degraded CBP conditions. The US-APWR procedures writer's guide includes requirements that ensure consistency and ease of transition between CBPs and paper procedures. Both CBPs and paper procedures are included in the V&V program, including transition for degraded HSI conditions, as described in Section 18.10.

18.8.2.5 Ergonomics Issues in Procedure Usage

The physical means by which operators access and use procedures, especially during operational events, is evaluated as part of the HFE design process. This criterion generally applies to both paper procedures and CBPs, although the nature of the issues differs somewhat depending on the implementation. For example, the process addresses the storage of procedures, the ease of operator access to the correct procedures, and the lay down of paper procedures for use in the MCR, RSR, TSC, and LCSs.

18.8.3 Results

The US-APWR procedure system report lists operating and emergency procedures developed for the US-APWR, with a brief descriptive summary for each procedure. Additionally, the report contains a summary of the content of the US-APWR procedure writer's guide.

Maintenance and control of updates to paper procedures and CBP are managed under the configuration control program of the US-APWR Quality Assurance Plan, as discussed in Section 18.1. Normal changes to CBPs, such as changes to procedure steps, do not affect the basic CBP software. Therefore, these changes are considered data changes and do not undergo software V&V, in accordance with the software life cycle management program (see Section 7.1). Changes to the basic CBP software do undergo V&V in accordance with the Software Lifecycle Management Program.

Procedure modifications are integrated across the full set of procedures; alterations in particular parts of the procedures are made to be consistent with other parts. Changes to procedures are documented and analyzed for their potential impact on HSI. Any procedure implementation issues that negatively affect Human Performance are identified as HEDs. The HEDs are tracked and dispositioned.

18.8.4 Combined License Information

No additional information is required to be provided by a COL Applicant In connection with this section.

COL 18.8(1) Deleted

18.8.5 References

18.8-1 U.S. Nuclear Regulatory Commission, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, NUREG-0800, Subsection 13.5.2.1 “Operating and Emergency Operating Procedures,” March 2007.

18.8-2 HSI System Description and HFE Process, MUAP-07007-P (Proprietary) and MUAP-07007-NP (Non-Proprietary), Revision 1, July 2007.

18.8-3 Plant Procedures, Inspection Procedure, IP-42700, November 1995.

18.8-4 Emergency Operating Procedures, Inspection Procedure, IP-42001, June 1991.

18.8-5 U.S. Nuclear Regulatory Commission, Guidelines for the Preparation of Emergency Operating Procedures, NUREG-0899, August 1982.

18.9 Training Program Development

18.9.1 Objectives and Scope

The objective of the training program is to develop training for plant operations and maintenance personnel. The training program:

- incorporates the elements of a systems approach to training
- evaluates the knowledge and skill requirements of personnel
- coordinates training program development with the other elements of the HFE design process, and
- implements the training in an effective manner that is consistent with human factors principles and practices

18.9.2 Methodology

The US-APWR Training Program addresses applicable requirements of NUREG-0800, Subsection 13.2.1 (Reference 18.9-1) that is necessary to ensure that training provided to operations and maintenance personnel is acceptable to maintain plant safety and respond to abnormal plant conditions. The detailed training program development process is documented in this section.

Reference 18.9-2 Section 5.9 provides a description of the US-APWR Training Program, including the methodology used to develop that program. The US-APWR Training Program is based on the training program for the Japanese APWR HSI. The Japanese and international standards, Japanese nuclear power plant operating experience, and NRC-directed operating considerations have been applied to the Japanese training program and are discussed in Reference 18.9-2.

The US-APWR Training Program is also based on the training program from the Japanese standard 4-loop PWR plant systems. The changes to this training program reflect the functional requirements analysis and function allocation, which is conducted based on the following:

- The degree to which the functions of the new plant design differ from those of the predecessors
- The extent to which difficulties related to plant functions are identified in the plant's operating experience and are addressed in the new plant and procedures design

The training program for the Japanese APWR HSI and the training program for the Japanese standard 4-loop PWR reflect plant operating experience in Japan and the V&V process conducted for the Japanese APWR HSI. These training programs are the basis for the US-APWR. However, the US-APWR Training Program is demonstrated to comply with NRC regulations, as stated in the following sections. The requirement for operator training simulator fidelity is described in Reference 18.9-2 Subsection 5.9.2.

18.9.2.1 General Training Approach

A systems approach to the training of plant personnel that addresses applicable guidance in Reference 18.9-1, Section 13.2 ("Training", 13.2.1), as defined in 10 CFR 55.4 (Reference 18.9-3), and as required by 10 CFR 52.78 (Reference 18.9-4) and 10 CFR 50.120 (Reference 18.9-5) is employed. The overall scope of training is defined to include the following:

- Categories of personnel to be trained (e.g., SRO) (Reference 18.9-6, Subsection 4.1.4)
- Specific plant conditions (e.g., normal, upset, and emergency, as identified in Section 18.4)
- Specific operational activities (e.g., operations, maintenance, testing, and surveillance, as identified in Section 18.4)
- HSIs (e.g., in the MCR, RSC, TSC, and LCSs)

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

Training addresses the following:

- The full range of positions of operations and maintenance personnel whose actions may affect plant safety:
  - Licensed operators
  - Non-licensed operators
  - Shift supervisors
  - Shift technical advisor
  - I&C technicians
  - Electrical maintenance personnel
  - Mechanical maintenance personnel
  - Radiological protection technicians
  - Chemistry technicians

  - Engineering support personnel

- The full range of plant functions and systems that may affect plant safety, including those that may be different from those in predecessor plants (e.g., passive systems and functions). This training encompasses maintenance activities related to technical specifications surveillances. For other maintenance activities, such as corrective maintenance, this is limited to removing equipment from service and restoring equipment to service

- The full range of relevant HSIs (e.g., MCR, RSC, and LCSs) including characteristics that may be different from those in predecessor plants (e.g., display navigation or operation of "soft" controls)

- The full range of plant conditions

The Systematic Approach to Training method described in References 18.9-7, 18.9-8, and 18.9-9 is used to develop training for the plant operations and maintenance staff.

18.9.2.2 Organization of Training

The roles of all organizations (e.g., MHI, plant owners, and vendors) are specifically defined for the development of training requirements, the development of training information sources, the development of training materials, and the implementation of the training program. For example, the role of the vendor may range from merely providing input materials (e.g., emergency procedure guidelines) to conducting portions of specific training programs. The qualifications of organizations and personnel involved in the development and conduct of training are defined. Facilities and resources, such as plant-referenced simulator and part-task training simulators, needed to satisfy training design requirements, and the guidance contained in ANSI/ANS 3.5 (Reference 18.9-10) and RG 1.149 (Reference 18.9-11), are defined.

18.9.2.3 Learning Objectives

Learning objectives for the training program reflect the desired performance after training. Learning objectives are derived from the following areas:

- Licensing Basis – Design control document/final safety analysis report, technical specifications, system description manuals and operating procedures, facility license and license amendments, LERs, and other documents identified by the staff as being important to training

- OER – Previous training deficiencies and operational problems that may be corrected through additional and enhanced training, and positive characteristics of previous training programs

- FRA/FA – Functions identified as new or modified

- Task Analysis – Tasks identified during task analysis as posing unusual demands including new or different tasks, and tasks requiring a high degree of coordination, high workload, or special skills

- HRA – Coordinating individual roles to reduce the likelihood and/or consequences of human error associated with risk-important HAs and the use of advanced technology

- HSI Design – Design features whose purpose or operation may be different from the past experience or expectations of personnel

- Plant Procedures – Tasks that have been identified during procedure development as being problematic (e.g., procedure steps that have undergone extensive revision as a result of plant safety concerns)

- V&V – Training concerns identified during V&V, including HSI usability concerns identified during validation or suitability verification and operator performance concerns (e.g., misdiagnoses of plant event) identified during validation trials

Learning objectives for personnel training address the knowledge and skill attributes associated with relevant dimensions of the trainee's job, such as interactions with the plant, the HSIs and procedures, and with other personnel. In developing the learning objectives for each training area, the dimensions of Table 10.1 of NUREG-0711 (Reference 18.9-12) are evaluated for applicability.

18.9.2.4 Content of Training Program

The design of the training program is defined to specify how learning objectives are conveyed to the trainee. The following parameters are included:

- The mixture of classroom lectures, simulator training, and on-the-job training, to convey particular categories of learning objectives

- The specific plant conditions and scenarios used in training programs

- Training implementation considerations, such as the temporal order and schedule of training segments

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

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

The training program addresses rules for decision-making related to plant systems, HSIs, and procedures. It includes rules for accessing and interpreting information and rules for interpreting symptoms of failures of systems, HSIs, and procedures. This training covers acquiring new decision-making rules and eliminating existing ones that are not appropriate to the design.

18.9.2.5 Evaluation and Modification of Training

Methods for evaluating the overall effectiveness of the training programs and trainee mastery of training objectives are defined, including written and oral tests and the review of personnel performance during walkthrough, simulator, and on-the-job exercises (or “table top reviews” during the design certification phase). The evaluation criteria for training objectives are defined for individual training modules. The methods for assessing overall proficiency are defined and coordinated with regulations, where applicable. The methods for verifying the accuracy and completeness of training course materials are defined. The procedures for refining and updating both the training content and conduct of training are established, and include procedures for tracking training course modifications.

18.9.2.6 Periodic Retraining

Personnel undergo periodic retraining. The periodicity of the retraining is established based on regulatory requirements (e.g., Reference 18.9-5, Appendix E) and Human Performance Monitoring (see Section 18.12).

18.9.3 Results

Training program modifications are integrated across the training program. The modification process ensures alterations in particular parts of the training program do not cause conflicts or inconsistencies with other parts. Those training program issues that negatively affect human performance are identified as HEDs and are tracked and dispositioned.

The training program report contains a synopsis of training modules developed for the US-APWR.

18.9.4 Combined License Information

No additional information is required to be provided by a COL Applicant in connection with this section.

COL 18.9(1) Deleted

18.9.5 References

18.9-1 U.S. Nuclear Regulatory Commission, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, NUREG-0800, Subsection 13.2.1 “Reactor Operator Requalification Program; Reactor Operator Training,” March 2007.

18.9-2 HSI System Description and HFE Process, MUAP-07007-P (Proprietary) and MUAP-07007-NP (Non-Proprietary), Revision 1, July 2007.

18.9-3 Definitions, NRC Regulations Title 10, Code of Federal Regulations, Part 55.4,

18.9-4 Contents of Applications; Training and Qualification of Nuclear Power Plant Personnel, NRC Regulations Title 10, Code of Federal Regulations, Part 52.78.

18.9-5 Training and Qualification of Nuclear Power Plant Personnel, NRC Regulations Title 10, Code of Federal Regulations, Part 50.120.

18.9-6 Selection, Qualification, and Training of Personnel for Nuclear Power Plants, ANSI/ANS 3.1, 1993.

18.9-7 Alternative Systematic Approaches to Training, DOE-HDBK-1074, U.S. Department of Energy, Washington, DC, January 1995.

18.9-8 Template for an Industry Training Program Description, NEI 06-13A, Nuclear Energy Institute, Washington, DC, Revision 1, March 2008.

18.9-9 Experience in the Use of Systematic Approach to Training for Nuclear Power Plant Personnel, IAEA-TECDOC-1057, IAEA, Vienna, Austria, December 1989.

18.9-10 Nuclear Power Plant Simulators for Use in Operator Training, ANSI/ANS 3.5, 1998.

18.9-11 Nuclear Power Plant Simulators Facilities for Use in Operator Training and License Examinations, Regulatory Guide 1.149, Revision 3, March 2001.

18.9-12 U.S. Nuclear Regulatory Commission, Human Factors Engineering Program Review Model, NUREG-0711, Revision 2, February 2004.

18.10 Verification and Validation

18.10.1 Objectives and Scope

V&V evaluations comprehensively determine that the US-APWR design conforms to HFE design principles and that it enables plant personnel to successfully perform their tasks to achieve plant safety and other operational goals. The V&V methodology has the following four major activities:

- Operational conditions sampling
- Design verification
- Integrated system validation
- HEDs Resolution

The scope of the V&V activity encompasses the MCR, RSC, TSC, EOF (information requirements and communications), and LCSs. All aspects of the MHI US-APWR V&V program are controlled by the appropriate sections of Reference 18.10-1.

18.10.2 Methodology

The V&V methodology addresses the following topics:

- Operational conditions sampling: the selection of operational scenarios to be used in V&V
- HSI design verification: the evaluation of the HSI design for meeting tasks requirements and HFE guidelines
- Integrated system validation: the evaluation of whether the integrated system (hardware, software, and crew) meets performance requirements
- HED resolution: the resolution of potential human performance issues identified in V&V evaluations

Reference 18.10-2 Section 5.10 provides a description of the US-APWR HFE V&V program, including the methodology used to develop that program. The US-APWR HFE V&V program is based on the V&V program for the Japanese APWR HFE, which encompasses the HSI design and procedure development. The Japanese and international standards, Japanese nuclear power plant operating experience, and NRC directed operating considerations have been applied to the V&V program and are discussed in Reference 18.10-2, Appendices A and B.

The US-APWR HSI and procedures are based on the Japanese APWR HSI and procedures. The changes to HSI and procedures are described in Sections 18.7 and

18.8, respectively. Therefore, the US-APWR HFE V&V program focuses on these changes.

18.10.2.1 Operational Conditions Sampling

This portion of the V&V process identifies a sample of operational conditions that is to be used as the basis for V&V activities. This sample:

- Includes conditions that are representative of the range of events that could be encountered during operation of the plant

- Reflects the characteristics that are expected to contribute to system performance variation

- Considers the safety performance of HSI components

The operational scenarios, events, transients, and accidents used in V&V are based on their risk importance. The complete basis for operational conditions sampling is described in Reference 18.10-2 Subsection 5.10.2.1. The selected operational conditions and their selection basis are documented in the HFE V&V implementation plan.

18.10.2.2 Design Verification

The operations conditions sample defines the scope of the V&V activities. The V&V activities are conducted using actual HSI displays generated by system software and actual HSI control panels. The aspects of the HFE design verification that are addressed are discussed below. Reference 18.10-3 is used as the principle source of detailed HFE design guidelines for the verification process.

- The design verification confirms that the inventory and characterization of all HSI components (alarms, controls, displays and related equipment) meet the HSI inventory and characterization requirements defined in the task analysis. This activity is sometimes referred to as HSI Task Support Verification

- The design verification confirms that the characteristics of the HSI, and the environment in which it is used, conform to HFE guidelines, as defined in the HSI design style guide. Reference 18.10-3 is used for confirmation of detailed characteristics that may not be included in the HSI design style guide

- The design verification identifies any inventory or characterization non-conformance. Non-conformances that are accepted are documented with appropriate evaluation criteria and the basis for those criteria. Non-conformances that are not accepted are identified as HEDs

Unique US-APWR HFE verification activities are not required for the basic HSI design characteristics of control, alarms, and indications, since this verification activity was conducted during Japanese human factors (HF) V&V program activities. HF verification is conducted for any changes to the Japanese HSI design.

18.10.2.3 Integrated System Validation

The integrated system validation is the process by which an integrated system design (i.e., hardware, software, and personnel elements) is evaluated to determine whether it acceptably supports safe operation of the plant. This process evaluates the acceptability of those aspects of the design that cannot be determined through such analytical means as HSI task-support verification and HFE design verification.

Integrated system validation is conducted using actual dynamic HSI with high fidelity plant model simulation of the operational conditions samples. Reference 18.10-2, Subsection 5.10.2.2.4, describes the process for the integrated system validation methodology.

The methods for integrated system validation include the following aspects of the validation methodology:

- Test objectives
- Validation test beds
- Plant personnel
- Scenario definition
- Performance measurement
  - Measurement characteristics
  - Performance measure selection
  - Performance criteria
- Test design
  - Coupling crews and scenarios
  - Test procedures
  - Test personnel training
  - Participant training
  - Pilot testing
- Data analysis and interpretation

- Validation conclusions

Plant personnel performing operational events for the validation use a simulator or other suitable representation of the system (referred to as a test bed) to determine its adequacy to support safety operations. The test bed of the MCR is a full-scope US-APWR control room simulator meeting the requirements of Reference 18.10-4. Other test beds modeling locations outside the MCR are represented by part task or limited scope simulations, meeting the guidelines of Reference 18.10-4, Appendix D, or by mockups or analysis. Deviations from the requirements of Reference 18.10-4 that are judged to be acceptable for the purposes of HSI validation, as compared to operator training, are documented and justified in the HSI V&V procedure.

The validation is undertaken after significant HEDs that were identified in verification reviews have been resolved, since these can negatively affect performance and the results of validation. A description of HEDs identified during the validation and their resolution is documented.

The US-APWR HSI design and procedures are based on the Japanese standard HSI design and procedures that were validated, as described in Reference 18.10-2, Appendices A and B. Validation for the US-APWR HSI design and procedures are conducted in two phases, as follows.

- Phase 1 - This phase validates the basic US-APWR HSI design.
  - For this phase, the Japanese standard HSI design and procedures are converted to the English language and English units of measure
  - This phase is conducted by a sample of US operations crews who are previously trained on the utilization of the Japanese HSI and procedures, and operation of the Japanese standard 4-loop PWR
  - Operational conditions samples used during this phase are those that assist with validation of the basic HSI design for cross-cultural differences and population stereotypes
  - This phase is documented in the U.S. Operator V&V Technical Report
- Phase 2 - This phase validates the final US-APWR HSI design and procedures.
  - This phase is conducted by US operations crews who are previously trained on the utilization of the US-APWR HSI and procedures, and operation of the US-APWR plant systems
  - Operational conditions samples used during this phase conform to all of the selection criteria in Subsection 18.10.2.1
  - This phase is documented in the US-APWR HF V&V report

18.10.2.4 Human Engineering Discrepancy Resolution

HED resolution is performed iteratively throughout all V&V activities. HEDs identified during a V&V activity are evaluated to determine if they must be resolved prior to conducting other V&V activities. The purpose of the HED resolution is to verify the adequate completion of the following tasks:

- Evaluation of HEDs to determine the need for their correction including their prioritization and organization responsible for resolution
- Identification of design solutions to address significant HEDs along with an indication of their current status (implemented or scheduled to be implemented)
- Determination of the HFE Program activities that must be re-performed to satisfy the requirements of the limited reapplication of the HFE analysis processes in Sections 18.3 through 18.6
- Verification of the implementation of the design solutions resolving HEDs including how the change complies with the V&V evaluation criteria

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

18.10.3 Results

The V&V Phase 1 results are to be documented in the US Operator V&V Technical Report. The Phase 2 results, to include V&V program staffing and resources, the detailed procedures for conducting the V&V program, the V&V program data, analysis, and results, identification, and resolution of HEDs, and the major conclusions from these activities along with their bases, are to be issued in the US-APWR HF V&V report.

18.10.4 Combined License Information

No additional information is required to be provided by a COL Applicant in connection with this section.

COL 18.10(1) Deleted

COL 18.10(2) Deleted

18.10.5 References

18.10-1 Quality Assurance Program (QAP) Description for Design Certification of the US-APWR, PQD-HD-19005, revision 1, Mitsubishi Heavy Industries, Ltd., October 2007.

18.10-2 HSI System Description and HFE Process, MUAP-07007-P (Proprietary) and MUAP-07007-NP (Non-Proprietary), Revision 1, July 2007.

18.10-3 U.S. Nuclear Regulatory Commission, Human-System Interface Design Review Guidelines, NUREG-0700, Revision 2, May 2002.

18.10-4 Nuclear Power Plant Simulators for Use in Operator Training, ANSI/ANS 3.5, 1998.

18.11 Design Implementation

18.11.1 Objectives and Scope

The objective of the design implementation is to demonstrate that the design that is implemented (i.e., the "as-built" design) accurately reflects the verified and validated design.

The scope of design implementation includes the effect on personnel performance resulting from design changes and provides the necessary support to ensure safe operations and that the as-built design conforms to the verified and validated design that resulted from the HFE process.

In this section, the referenced changes after V&V apply to the changes made to the US-APWR design following V&V.

18.11.2 Methodology

The detailed HFE design implementation process is performed and documented as described below.

The design implementation methodology includes the following criteria:

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

- The potential impact on HAs is assessed and a risk significance level is assigned in accordance with the criteria in Reference 18.11-1

- All HFE-related issues documented in the issue tracking system are verified to be adequately addressed

18.11.3 Results

Facility design changes are documented and analyzed for their potential impact on HSIs. Those design implementation issues that negatively impact human performance are identified as HEDs and are tracked and dispositioned. HFE design modifications are documented in a periodic status report.

18.11.4 Combined License Information

No additional information is required to be provided by a COL Applicant in connection with this section.

COL 18.11(1) Deleted

COL 18.11(2) Deleted

18.11.5 References

18.11-1 U.S. Nuclear Regulatory Commission, Guidance for the Review of Changes to Human Actions, NUREG-1764, Revision 1, September 2007.

18.12 Human Performance Monitoring

18.12.1 Objectives and Scope

Human performance monitoring applies after the plant is in operation. Human performance monitoring within the scope of this program specifically applies to the following:

- Time critical operator actions
- Correct diagnosis of abnormal plant events
- Accuracy of procedure execution

Monitoring of human performance in other areas is within the scope of other plant programs (such as, “Fitness for Duty”).

18.12.2 Methodology

A human performance monitoring strategy is developed and documented. The US-APWR HFE procedure guides the human performance monitoring for the life of the plant and the process to identify and disposition human performance issues. This human performance monitoring procedure is applicable after the completion of integrated HSI validation and operator training.

This process evaluates the impact of facility design and operating changes and addresses the following topics:

- Human performance monitoring includes confirmation of the following criteria:
  - Effectiveness of HSIs
  - Personnel performance impacts of HSI, procedure, and training changes
  - Operator actions meet time and performance criteria
  - Human performance criteria established during integrated system validation are maintained
- Human performance trending includes the following:
  - Performance degradation
  - Failures
  - Detection sensitivity
  - Safety Importance
- Human performance evaluation criteria includes the following:

- Specific cause determination
- Safety Importance
- Feedback of information
- Corrective actions

18.12.3 Results

Human performance issues are identified as HEDs and are tracked and dispositioned in accordance with the site specific QA program.. HED disposition is documented in a periodic status report.

18.12.4 Combined License Information

No additional information is required to be provided by a COL Applicant in connection with this section.

COL 18.12(1) Deleted