APR1400
DESIGN CONTROL DOCUMENT TIER 2

CHAPTER 18
HUMAN FACTORS ENGINEERING

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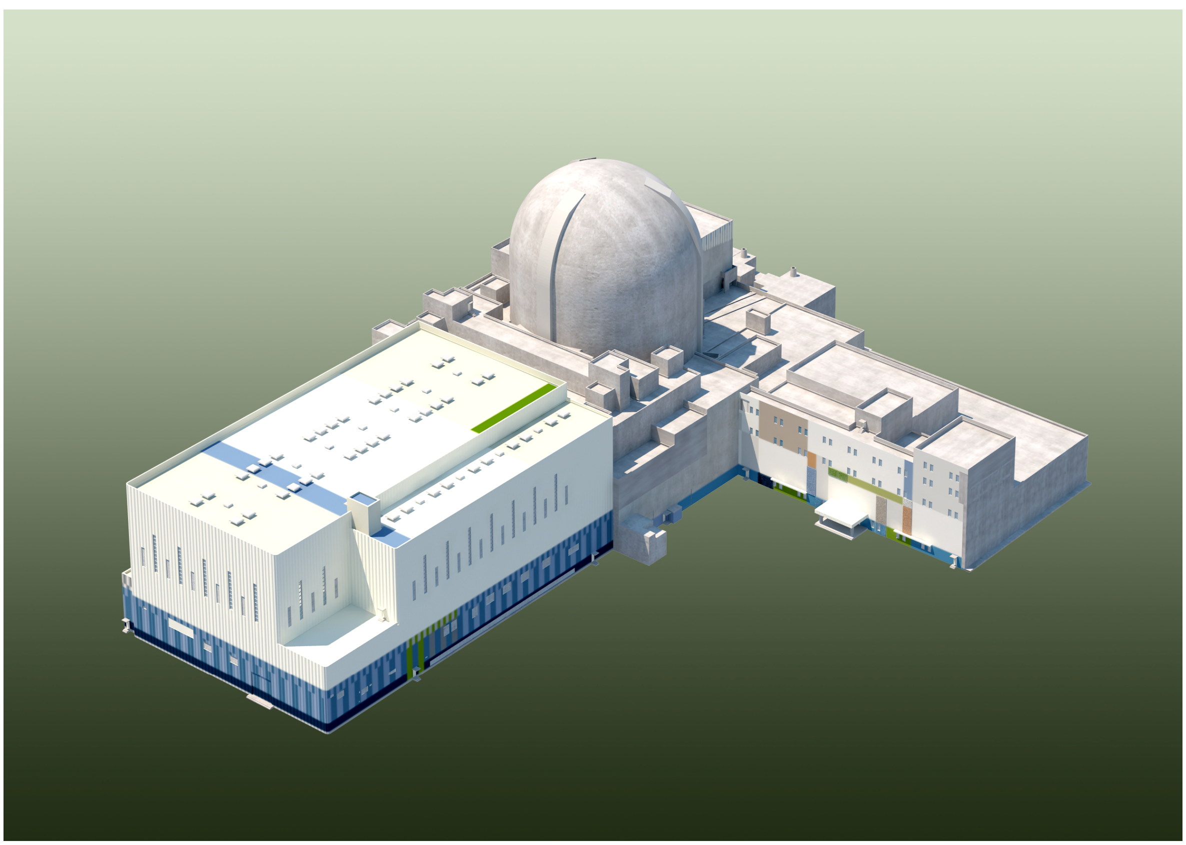

KOREA ELECTRIC POWER CORPORATION
KOREA HYDRO & NUCLEAR POWER CO., LTD

CHAPTER 18 – HUMAN FACTORS ENGINEERING

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ACRONYM AND ABBREVIATION LIST

ANSI	American National Standards Institute
APR	Advanced Power Reactor
APWR	Advanced Pressurized Water Reactor
ATWS	Anticipated Transients Without Scram
BISI	Bypassed and Inoperable Status Indication
CAP	Corrective Actions Program
CBP	Computer-Based Procedure
CFM	Critical Function Monitoring
CFR	Code of Federal Regulations
COL	Combined License
CSF	Critical Safety Function
EO	Electric Operator
EOF	Emergency Operations Facility
EOG	Emergency Operating Guideline
EOP	Emergency Operating Procedure
EPRI	Electric Power Research Institute
ESF	Engineered Safety Features
FPD	Flat Panel Display
FRA/FA	Functional Requirements Analysis and Function Allocation
HA	Human Action
HED	Human Engineering Discrepancy
HF	Human Factors
HFE	Human Factors Engineering
HFEPP	Human Factors Engineering Program Plan
HRA	Human Reliability Analysis
HSI	Human-System Interface
HTA	Hierarchical Task Analysis
I&C	Instrumentation and Control
ICR	Information and Control Requirement

IEEE	Institute of Electrical and Electronics Engineers
IHA	Important Human Action
IPS	Information Processing System
ISV	Integrated System Validation
ITS	Issue Tracking System
KHNP	Korea Hydro & Nuclear Power Co., Ltd.
LCS	Local Control Station
LDP	Large Display Panel
MCR	Main Control Room
NRC	Nuclear Regulatory Commission
OECD	Organisation for Economic Co-operation and Development
OER	Operating Experience Review
PRA	Probabilistic Risk Assessment
QIAS	Qualified Indication and Alarm System
QIAS-N	Qualified Indication and Alarm System - Non-safety
RIHA	Risk-Important Human Action
RO	Reactor Operator
RSR	Remote Shutdown Room
SKN 3&4	Shin-Kori Nuclear Power Plant Unit 3 and 4
SPDS	Safety Parameter Display System
SRO	Senior Reactor Operator
SS	Shift Supervisor
STA	Shift Technical Advisor
TA	Task Analysis
TO	Turbine Operator
TSC	Technical Support Center
V&V	Verification and Validation
VDU	Visual Display Unit

CHAPTER 18 – HUMAN FACTORS ENGINEERING

18.1 Human Factors Engineering Program Management

18.1.1 General Human Factors Engineering Program Goals and Scope

The goal of the APR1400 human factors engineering (HFE) program is to provide reasonable assurance that the HFE design is properly developed and effectively implemented in the APR1400 design.

The HFE program objectives for the nuclear power plant design are that it is human-centered, incorporates HFE principles and methods, and is developed according to a systematic approach.

In accordance with the applicable requirements of the HFE elements of NUREG-0711 (Reference 1), the *[Human Factors Engineering Program Plan]** (HFEPP) (Reference 2) provides reasonable assurance that the human-system interface (HSI) design effectively supports the operator and minimizes the potential for consequential operator errors.

The HFE program will be in effect from the start of the HFE design cycle through completion of initial plant startup test program.

HFE Program Management Goals

Section 1.1 of the HFEPP defines the goals, requirements, and criteria of the HFE program management element.

Goals represent the idealized function or purpose of the element. Requirements operationalize the goals and are pragmatic and concrete. Requirements are met by adhering to the criteria, which are objectively verifiable quantities or qualities of acceptability.

<u>Human-centered Design Goals</u>

Subsection 2.4.1(1) of NUREG-0711 identifies four generic human-centered design goals, which are the general design objectives for the HSI expressed in terms of human performance. Stated as generalities, the goals are to be objectively defined and to serve as criteria for test and evaluation activities.

The design goals in NUREG-0711 are as follows:

a. Personnel tasks can be accomplished within time and performance criteria.

b. The HSIs, procedure, staffing and qualifications, training and management, and organizational arrangement support personnel situational awareness.

c. The design will support personnel in maintaining vigilance over plant operations and provide acceptable workload levels to minimize periods of operator under-load and over-load.

d. The HSIs will minimize personnel error and support error detection and recovery capability.

To accomplish the above goals, the HFE program management element includes the following:

a. General HFE program goals and scope

b. HFE design team and organization

c. HFE process and procedures

d. HFE issues tracking

e. HFE technical program

18.1.1.1 Assumptions and Constraints Identification

A fundamental assumption of the APR1400 HFE design is that it is possible to operate the plant during postulated plant operating modes with the following personnel in the main control room (MCR): one reactor operator (RO) with a reactor operator license, one turbine operator (TO) with a reactor operator license, one non-licensed electric operator (EO), one shift supervisor (SS) with a senior reactor operator license, and one shift technical advisor (STA) with a senior reactor operator license.

The above MCR staffing meets the regulatory requirements of 10 CFR 50.54(m)(2)(i) (Reference 3).

The HSI is designed to meet the requirements of 10 CFR 50, Appendix A (Reference 4), and to accommodate the MCR staffing described above. The layout of the MCR is based on the limited need for access to the MCR by other plant personnel while facilitating the effective interfacing of MCR staff with the field equipment operators and maintenance staff.

The MCR environment is designed using human engineering principles to provide a comfortable, professional atmosphere for the operators that enhances their effectiveness. An attention is also given to colors and lighting levels that will enhance operator alertness and minimize operator fatigue.

The APR1400 design includes an advanced control room with fully computerized HSI resources containing redundant compact operator consoles, a large display panel, computer-based procedures, soft controls, and a safety console with a minimum number of fixed-position displays and controls, which are described in Section 18.7.

The schedule, milestones, and duration of the APR1400 HFE program are described in Section 3.1 of the HFEPP.

18.1.1.2 Applicable Plant Facilities

The HFE program addresses the following facilities:

a. Main control room (MCR)

b. Remote shutdown room (RSR)

c. Technical support center (TSC)

d. Emergency operations facilities (EOFs) (communication and information requirements only)

e. Local control stations (LCSs) associated with important human actions (IHAs)

The elements of the HFE program are applied through a graded approach to facilities other than the MCR and RSR. The graded approach for the application of HFE program to APR1400 plant facilities is shown in Table 1 of the HFEPP. As described in the HFEPP, the graded approach involves applying HFE program elements at different levels of detail and completeness, based on the importance of the facility.

18.1.1.3 Applicable HSIs, Procedures, and Training

The APR1400 HSIs are developed in accordance with the HFEPP. Procedures and training programs are developed in accordance with Chapter 13. The HFEPP identifies inputs for the programs.

18.1.1.4 Applicable Plant Personnel

Plant personnel addressed by the HFEPP include licensed control room operators as defined in 10 CFR 55 (Reference 5).

18.1.2 HFE Design Team and Organization

18.1.2.1 Responsibility

The multi-disciplinary HFE design team includes the architectural engineering group, operations group, and nuclear steam supply system group as shown in Figure 18.1-1.

The HFE design team is responsible for the following activities with respect to the HFE program scope:

a. Developing all HFE plans and procedures

b. Reviewing all HFE design, development, test, and evaluation activities

c. Initiating, recommending, and providing solutions for problems identified in the implementation of the HFE activities

d. Verifying implementation of HFE design team recommendations

e. Providing reasonable assurance that all HFE activities comply with the HFE plans and procedures

f. Scheduling HFE-related activities and milestones

g. Providing and confirming adherence to applicable HFE design guidance and requirements

h. Integrating HFE activities throughout the APR1400 design

i. Designing the HSI

18.1.2.2 Organizational Placement and Authority

The organization of the HFE design team is shown in Figure 18.1-1.

The HFE design team has the authority to provide reasonable assurance that the HFE program is fully implemented in accordance with the HFEPP and that the HSI design complies with the human-centered design goals as stated in Subsection 18.1.1.

HFE Design Team Leader

The HFE design team leader serves as the technical project manager for the HFE design process and is responsible for the overall HSI design and integration with other design activities.

The HFE design team leader manages the HFE development schedule and makes decisions on unresolved issues between the HFE design team and other design teams. When resolution cannot be achieved among the design teams, the HFE design team leader refers the unresolved issue to the project manager for resolution.

HFE Design Coordinator

The HFE coordinator works with the HFE designer to resolve human engineering discrepancies (HEDs) and manages HFE design team action items.

HFE Designer

The HFE designer is responsible for developing the human factors design, conforming the design to the design requirements, and providing reasonable assurance that human factors are integrated into the design.

The HFE designer reviews design documents and provides comments based on areas of expertise. The designer also participates in design review meetings related to HSI development.

18.1.2.3 HFE Design Team Composition

The HFE design team is a multidisciplinary team that includes staff from the following disciplines: electrical engineering, mechanical engineering, nuclear engineering, architectural engineering, operations, computer systems engineering, and probabilistic risk assessment. Figure 18.1-1 shows the composition of the HFE design team.

18.1.2.4 HFE Design Team Staffing

The minimum qualifications and job descriptions of the members of HFE design team, including the documentation of the qualifications and job descriptions, are according to Section 4.0 of the Project Procedures Manual (Reference 6) and Section 2.4 of the HFEPP.

18.1.3 HFE Design Process

18.1.3.1 General Process Procedures

The design team executes its responsibilities according to the following:

a. The design processes for the internal management of the team and HSI design changes are described in the Project Procedures Manual.

b. The HFE management and design decision processes are described in Subsection 3.2.1 of the HFEPP. HFE activities are assigned to the cognizant engineering group, and each group assigns the activities to individual members.

The design review process for HFE products is shown in Figure 18.1-2.

18.1.3.2 Process Management Tools

Tools are provided to facilitate communication across design teams and to enhance consistency and efficiency. The review and comment system and the issue tracking system (ITS) are two process management tools for the development of HFE designs.

The review and comment system is used by designers and reviewers to provide comments and opinions on the HSI design and design documents.

The ITS is used to track design issues identified during the HFE design process.

18.1.3.3 Integration of the HFE Design to Other Plant Design Activities

The integration of design activities is based on the inputs from other plant design activities to the HFE program and the outputs from the HFE program to other plant design activities.

Integration of HFE designs into other plant design activities is performed in accordance with the Korea Hydro & Nuclear Power Co., Ltd. (KHNP) Quality Assurance Program Description for the APR1400 Design Certification (Reference 7).

18.1.3.4 HFE Program Milestones

HFE milestones, which are described in Section 3.1 of the HFEPP, are identified so that an evaluation of the effectiveness of the HFE effort can be made at critical checkpoints and the relationship to the integrated plant sequence of events can be shown.

The schedule for HFE program tasks showing the relationships between HFE elements and activities, products, and reviews is included in the HFEPP.

18.1.3.5 HFE Documentation

The HFE documents consist of HFE implementation plans, results summary reports, HFE design-related technical reports, and drawings.

HFE Implementation Plans and Results Summary Reports

a. *[Human Factors Engineering Program Plan]**

b. *[Operating Experience Review Implementation Plan]** and Results Summary Report

c. *[Functional Requirements Analysis and Function Allocation (FRA/FA) Implementation Plan]** and Results Summary Report

d. *[Task Analysis Implementation Plan]**

e. *[Staffing and Qualifications Implementation Plan]**

f. *[Treatment of Important Human Actions Implementation Plan]**

g. *[HSI Design Implementation Plan]**

h. *[Human Factors Verification and Validation Implementation Plan]**

i. *[Design Implementation Plan]**

j. *[Human Performance Monitoring Implementation Plan]**

The review and comment system maintains the documents listed above and makes the documents accessible to designers and reviewers.

18.1.3.6 Subcontractor HFE Efforts

HFE requirements are included in subcontracts to support the HFE design. Subcontractor compliance with HFE requirements is demonstrated in the procurement specifications of the HSI system.

Procurement specifications for HFE design requirements and a style guide are provided to the subcontractor in a standard appendix. Subcontractor management is described in the Project Procedures Manual.

18.1.4 HFE Issues Tracking

The ITS receives inputs from the operating experience review (OER) and issues that are identified during the analysis, design development, and verification and validation (V&V) stages including HEDs.

The HFE design team is responsible for issue logging, tracking, and resolution processes. For each issue entered into the database, cognizant engineers are assigned to resolve the issues. The process for the HFE issue management is shown in Figure 18.1-4. Section 4.2 of the HFEPP provides threshold criteria that determine when issues are entered into the system.

Once entered, issues are tracked until the potential for negative effects on human performance are reduced to an acceptable level.

The HFE design team establishes closure criteria for each issue.

18.1.5 Technical Program

Implementation plans, analyses, and evaluations for the following HFE elements are developed and shown in Figure 18.1-3:

a. Operating experience review

b. Functional requirements analysis and function allocation

c. Task analysis

d. Staffing and qualifications

e. Treatment of IHAs

f. HSI design

g. Human factors V&V

h. Design implementation

i. Human performance monitoring

The HFE standards and specifications that are sources of HFE requirements are identified and described in the HFEPP.

Evaluations and analyses, with the use of the simulator and similar plant operators, provide inputs for determining the adequacy of the HSI design. Testing and evaluation of HSI designs are used throughout the HSI development.

Details of the design testing and evaluations using a simulator are described in Subsection 18.7.2.6.

18.1.6 Combined License Information

No COL information is required with regard to Section 18.1.

18.1.7 References

1. NUREG-0711, Revision 3, "Human Factors Engineering Program Review Model," U.S. NRC, Washington, DC, November 2012.

2. *[KHNP, APR1400-E-J-NR-12002-P, "Human Factors Engineering Program Plan," September 2013.]**

3. 10 CFR 50.54, "Conditions of Licenses," U.S. NRC, Washington, DC.

4. 10 CFR 50, Appendix A, "General Design Criteria for Nuclear Power Plants," U.S. NRC, Washington, DC.

5. 10 CFR 55, "Operators' Licenses," U.S. NRC, Washington, DC.

6. KHNP, "Project Procedures Manual," September, 2013.

7. KHNP, APR1400-K-Q-TR-11005-N, "KHNP Quality Assurance Program Description for APR1400 Design Certification," 2011.

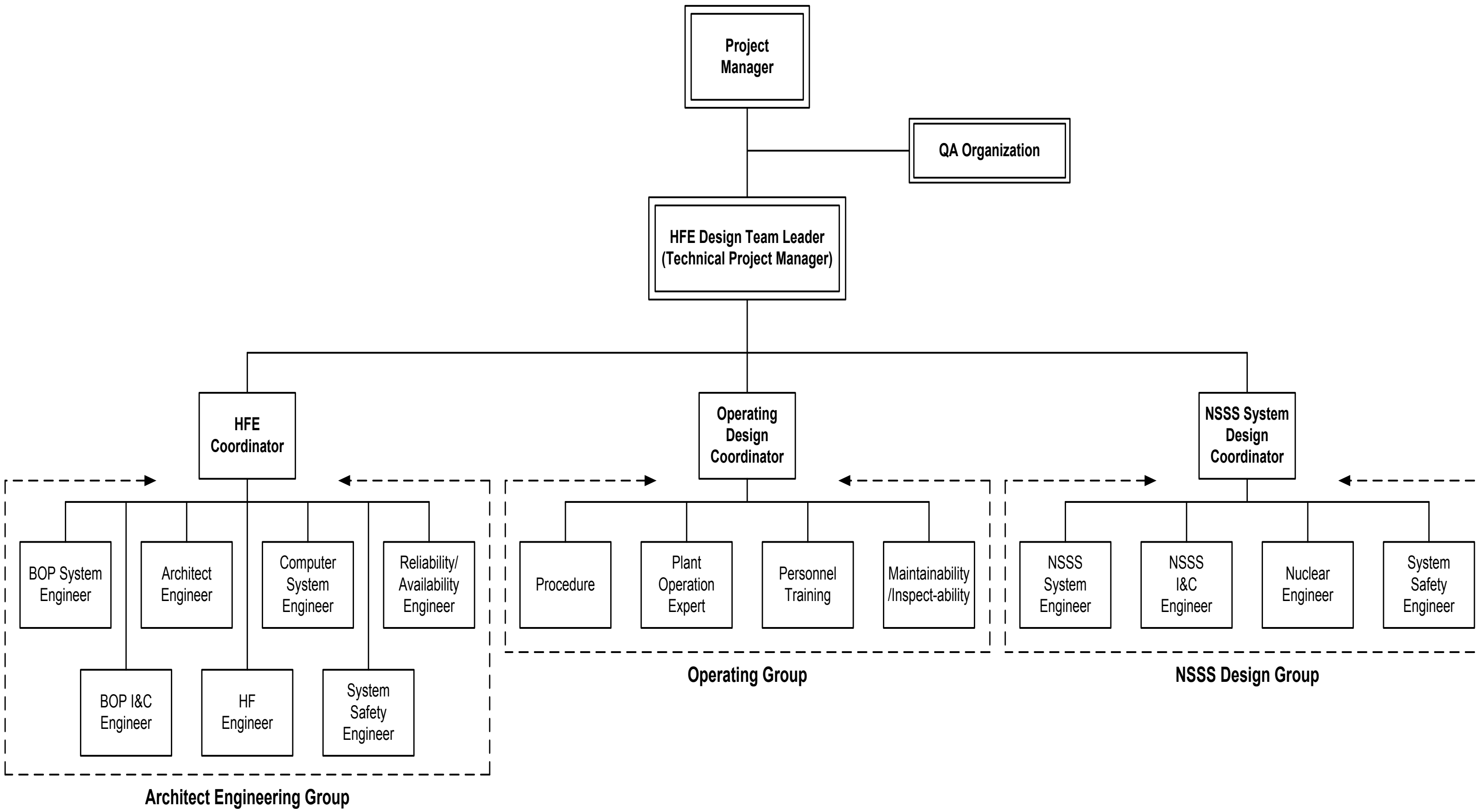

Figure 18.1-1 APR1400 HFE Design Team Organization

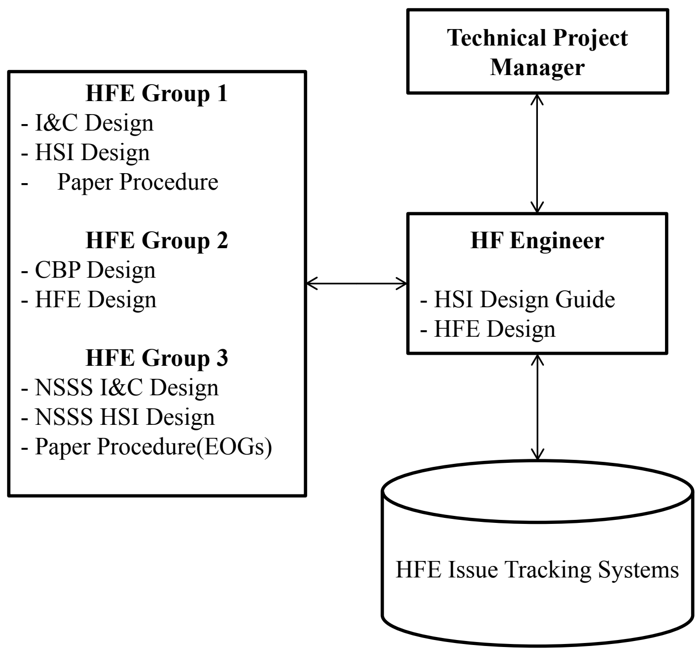

Figure 18.1-2 Work Flows for HFE Design Team

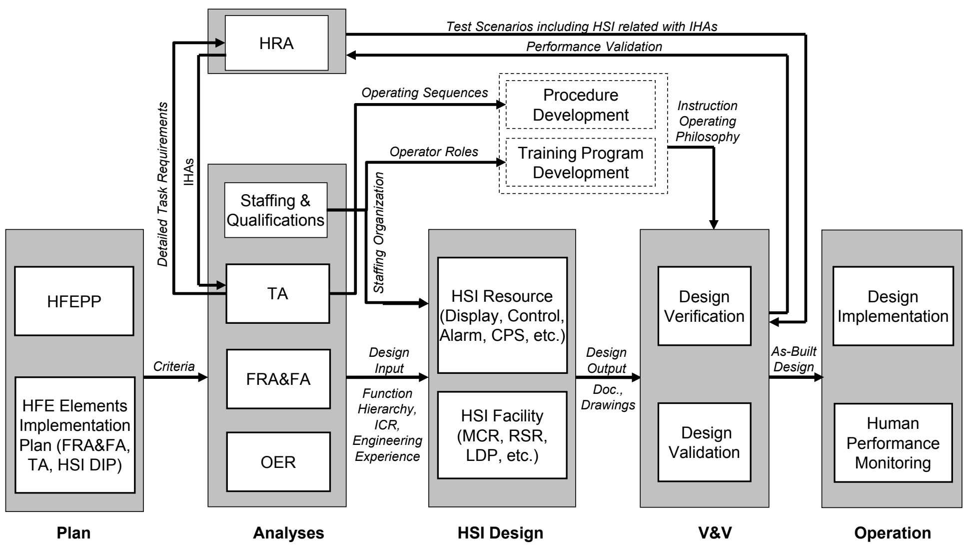

Figure 18.1-3 HFE Design Process

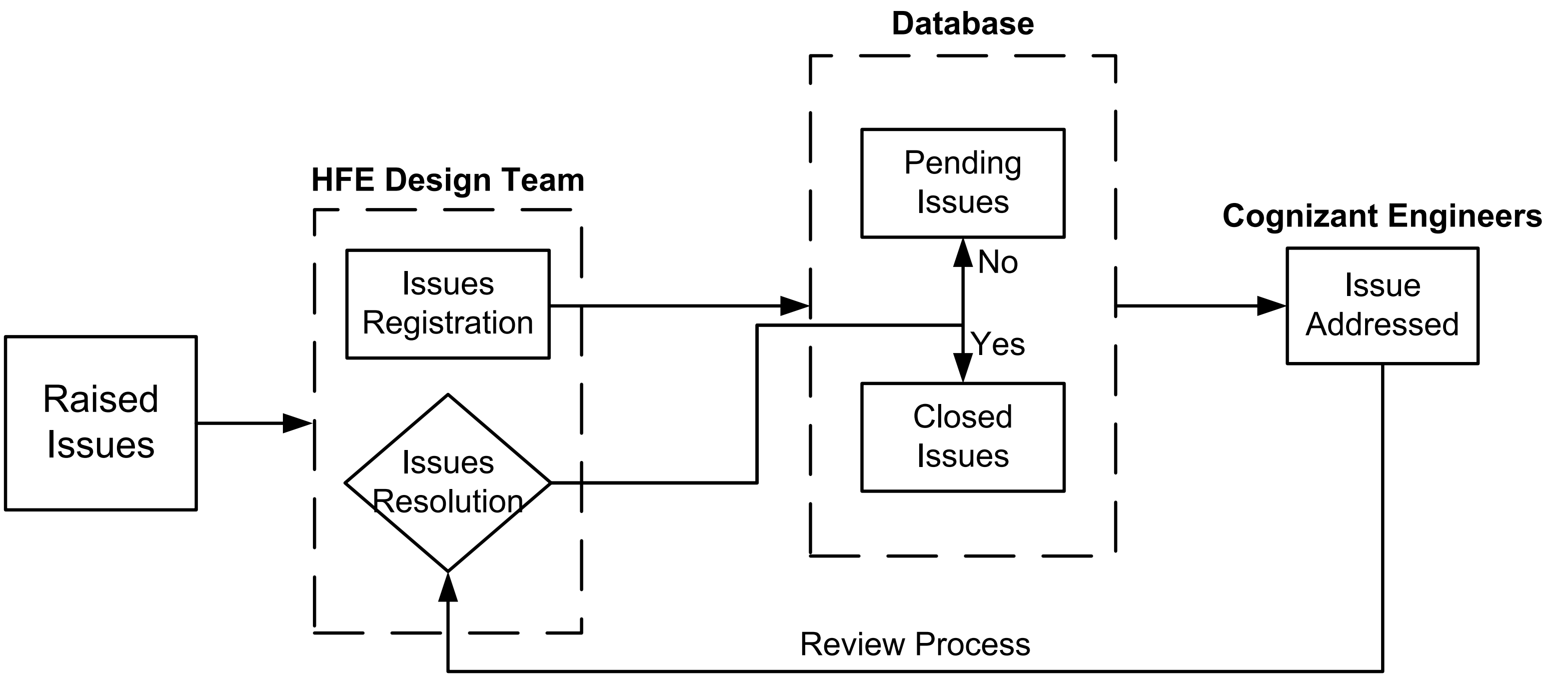

Figure 18.1-4 Issue Tracking System

18.2 Operating Experience Review

18.2.1 Objectives and Scope

The objective of operating experience review (OER) is to provide reasonable assurance that HFE-related problems or issues encountered in previous human-system interface (HSI) and control room facility designs similar to the APR1400 design, as well as other existing nuclear power plants, are successfully addressed.

OER issues are provided to the HFE design team and related system designers at the beginning of the design so OER issues can be incorporated into the HFE design.

The scope of the OER includes the following categories:

a. Predecessor plants and systems

b. Recognized industry HFE issues

c. Related HSI technology

d. Issues identified by plant personnel

e. Important human actions (IHAs)

18.2.2 Methodology

18.2.2.1 OER Process

The HFE design team reviews the OER and identifies the OER issues that are relevant to the APR1400 design. The review provides valuable input to the HSI design. The OER results are incorporated into the HFE design. The incorporation efforts are documented, and the operating experience issues that are identified as being relevant to the HFE design and that have not been considered in the design are added to the issues tracking system (ITS) (see Subsection 18.1.4) for resolution.

The OER is performed in the following steps:

a. Identification of OER issues

1) HFE-related information from licensee event reports, safety evaluation reports, significant operating experience reports, corrective action program, and plant staff input is reviewed by the HFE design team.

2) OER issues related to the APR1400 HSI design are identified.

b. Incorporation of relevant OER issues into the HFE design

1) The HFE design team delivers OER issues to the HSI designer

2) The HSI designer's response for design solutions is assessed by the HFE design team.

3) Relevant OER issues are incorporated into the HSI design

4) Open OER issues are tracked

Various HFE-related design issues are identified in terms of HSI design resources and HFE elements. The issues that are directly relevant are evaluated in terms of their importance of HFE aspects with respect to plant and personnel performance according to the *[Operating Experience Review Implementation Plan]** (Reference 1).

OER issue that is related to safety is evaluated as Class 1, and other issues are evaluated as Class 2 or 3.

Class 1 issues contain information that is addressed in the additional design effort and a review of the resolution during human factors verification and validation activities. The issues that are directly relevant are evaluated for their overall importance to plant and personnel performance.

Class 2 issues are addressed to provide improved consistency and to avoid the cumulative effects of significant issues, but the information is not deemed to be essential.

Class 3 issues are for information only so they can be re-evaluated in light of future changes.

Figure 18.2-1 shows the process for selecting the OER issues that need continuous issue tracking. In the figure, the class is determined by the HFE design team as follows:

a. Class 1: Issue that needs continuous tracking.

b. Class 2: Issue that needs to be audited by the HFE design team.

c. Class 3: Issue that needs to be reviewed for quality improvement and is for HSI designer reference only.

18.2.2.2 Predecessor Plants and Systems

HFE-related OER issues in previous plants and designs are identified and analyzed so the issues can be avoided in the APR1400 design.

OER issues for predecessor plants and systems are identified through the following sources:

a. Design issues from predecessor plants (i.e., Korean pressurized water reactors)

b. Unresolved design issues from a reference plant (i.e., Shin-Kori nuclear power plant units 3&4 (SKN 3&4))

18.2.2.3 Recognized Industry HFE Issues

The OER describes the operating experience associated with recognized industry issues. OER issues for recognized industry fields are identified through the review categories listed below as described in NUREG/CR-6400 (Reference 2).

a. Unresolved safety issues and generic safety issues

b. Three Mile Island issues

c. NRC generic letters and information notice

d. NUREG-1275 series, Volume 1 through 14 (Reference 3)

e. Low-power and shutdown operations

f. Operating plant event reports

18.2.2.4 HSI Technology

The OER describes the operating experience associated with the proposed HSI designs. OER issues for HSI technology are identified through the following review resources:

a. Electric Power Research Institute (EPRI) research documents (References 4 through 8)

b. Experimental Evaluation of the Computerized Procedure System (Reference 9)

c. Hybrid Human-System Interface: Human Factors Considerations (Reference 10)

d. Control Room Systems Design for Nuclear Power Plants (Reference 11)

e. NUREG-0711, Human Factors Engineering Program Review Mode (Reference 12)

f. Organisation for Economic Co-operation and Development (OECD) Specialists Meeting, Human Factors and Operation Aspects in Computerization of the Control Room: A French Safety View Based on N4 Experience (Reference 13)

18.2.2.5 Issues Identified by Plant Personnel

Plant personnel interviews are conducted to determine operating experience related to predecessor plants and systems. OER issues obtained during the interviews are reviewed

and documented by the HFE design team. The following topics are included in the interviews:

a. Plant operation

   1) Normal plant evolutions (e.g., startup, full power, shutdown)

   2) Instrument failures (e.g., safety system logic and control unit, fault tolerant controller, communication systems)

   3) HSI equipment and processing failure (e.g., loss of displays, loss of information processing system, loss of large display panel)

   4) 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, safety relief valve transients)

   5) Accidents (e.g., main steam line break, positive reactivity addition, control rod insertion at power, control rod ejection, anticipated transients without scram [ATWS], various-sized loss-of-coolant accidents [LOCA])

   6) Reactor shutdown and cooldown using the remote shutdown system

b. HFE-related design topics

   1) Alarm and annunciation

   2) Display

   3) Control and automation

   4) Information processing and job aids

   5) Communication with plant personnel and other organizations

6) Procedures, training, staffing and qualifications, and job design

18.2.2.6 Important Human Actions

The OER includes IHAs that have been identified at similar plants or the result of human error that use technologies that are similar to the technologies in the HSI design. The OER identifies IHAs by using the process described in Subsection 18.2.2.1.

18.2.2.7 Issue Analysis, Tracking, and Review

The issues identified during the OER are entered into the HFE issues tracking system (see Subsection 18.1.4).

18.2.3 Results

An example of an OER issue extracted from OER source data is provided in Table 18.2-1. OER results are documented in the Results Summary Report.

18.2.4 Combined License Information

No COL information is required with regard to Section 18.2.

18.2.5 References

1. *[KHNP, APR1400-E-J-NR-12203-P, "Operating Experience Review Implementation Plan," September 2013.]**

2. NUREG/CR-6400, "HFE Insights for Advanced Reactors Based Upon Operating Experience," Brookhaven National Laboratory, January 1997.

3. NUREG-1275, "Causes and Significance of Design-Basis Issues at U.S. Nuclear Power Plants," NRC, 2000.

4. EPRI TR-1003090, "I&C Upgrade – Implementation Experience and Perspective," Interim Report, Palo Alto, CA: Electric Power Research Institute, December 2001.

5. EPRI TR-1003322, "Guidance for Incorporating Organizational Factors into Nuclear Power Plant Risk Assessments," Final Report, Palo Alto, CA: Electric Power Research Institute, December 2002.

6. EPRI TR-1003329, "Template for Performing Human Reliability Analyses," Final Report, Palo Alto, CA: Electric Power Research Institute, June 2002.

7. EPRI TR-1007794, "Critical Human Factors Technology Needs for Digital Instrumentation and Control and Control Room Modernization," Final Report, Palo Alto, CA: Electric Power Research Institute, March 2003.

8. EPRI TR-1008122, "Human Factors Guidance for Control Room and Digital Human-System Interface Design and Modification," Final Report, Palo Alto, CA: Electric Power Research Institute, November 2004.

9. OECD, Halden Reactor Project, "Experimental Evaluation of the Computerized Procedure System," HWP-277, December 1990.

10. Brookhaven National Laboratory, "Hybrid Human-System Interface: Human Factors Considerations," December 1996.

11. IAEA-Techdoc-812, "Control Room Systems Design for Nuclear Power Plant," July 1995.

12. NUREG-0711, Revision 3, "Human Factors Engineering Program Review Model," November 2012.

13. OECD Specialists Meeting, Human Factors and Operation Aspects in Computerization of the Control Room: A French Safety View Based on N4 Experience," August 1999.

Table 18.2-1

Example of OER Issue and Resolution for the APR1400

Category/No.	Issues	HSI System	Rationale	Resolution	Completion Status
1 [(1)] / 70	AEOD/S92-12:54 August 26, 1992, Draft 2-A: Loss of Annunciator and Computer Availability	Alarm	Visual Display Unit (VDU) - based alarm system is not available to provide access to any alarm message because it is not shown on the current display page.	The information processing system (IPS) and qualified indication and alarm system (QIAS) provide redundant and diverse annunciator functions. Validation of the alarm systems provides reasonable assurance that the operator can use them effectively under all operational conditions including complete loss of the IPS and loss of a QIAS segment.	Resolved item

(1) Issues identified in Nuclear Regulatory Authority Documents (Analysis and Evaluation of Operational Data)

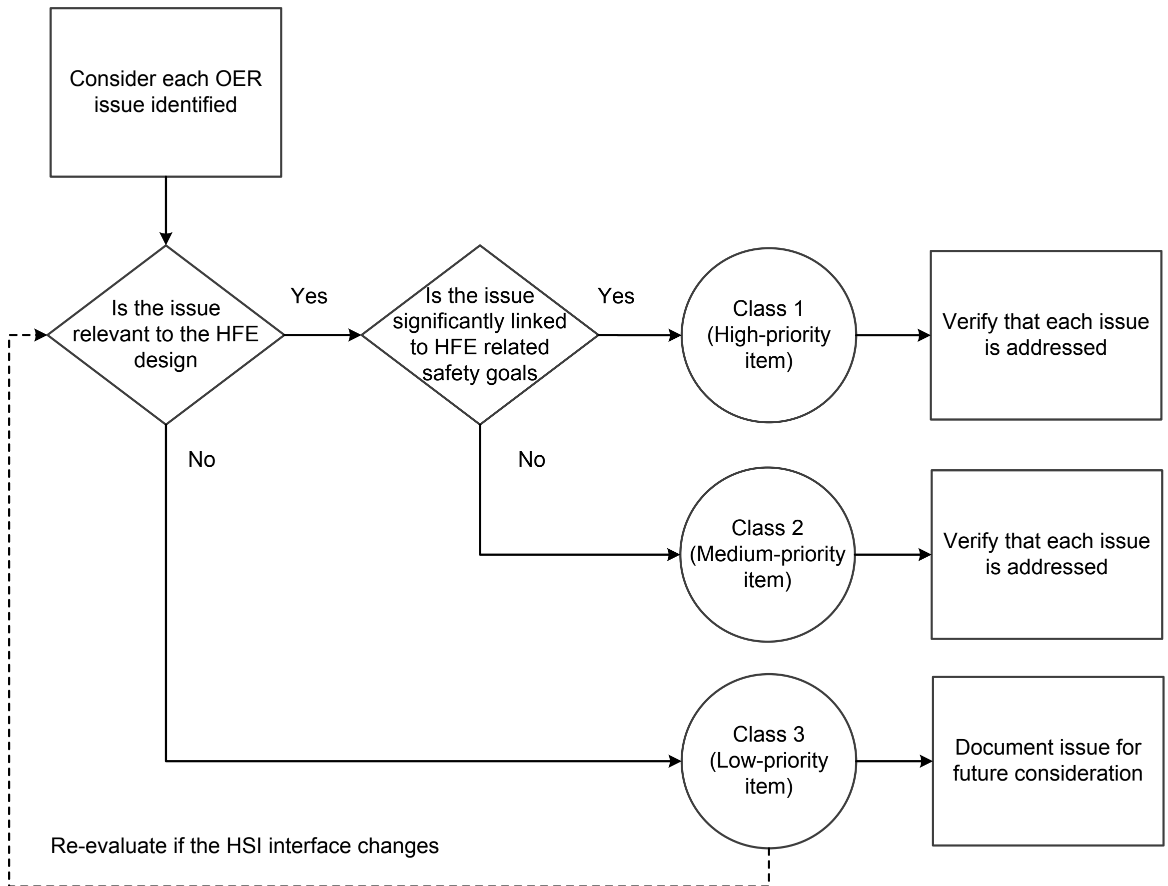

Figure 18.2-1 Selection Process of OER Issues for HEDs

18.3 Functional Requirements Analysis and Function Allocation

18.3.1 Objectives and Scope

The objectives of the functional requirements analysis and function allocation (FRA/FA) are to (1) define the plant functions that must be performed to satisfy plant safety and power production objectives and (2) to confirm that the allocation of these functions to human and system resources has resulted in personnel roles that take advantage of human strengths and avoid human limitations.

The FRA/FA for the APR1400 is based on the results of the analyses of the System 80+ plant. In addition, differences in success paths, or how a success path is achieved between the APR1400 and System 80+, are included in the FRA/FA along with the regulatory requirements that have been implemented since the System 80+ design.

18.3.1.1 Functional Requirements Analysis

The scope of the FRA includes the systems and components that are important to safety and required for safe shutdown and systems required for power production.

The FRA is conducted to:

a. Determine the objectives, performance requirements, and constraints of the design

b. Define the high-level functions that must be accomplished to meet the design objectives and desired performance

c. Define the relationships between high-level functions and plant systems (e.g., plant configurations or success paths) responsible for performing the function

d. Provide a framework for understanding the role of controllers (i.e., personnel or system elements) for controlling the plant

18.3.1.2 Function Allocation

The scope of the FA includes the assignment of control functions to personnel (e.g., manual control), system elements (e.g., automatic control or passive, self-controlling resources), and combinations of personnel and system elements (e.g., shared control or automatic systems with manual backup).

18.3.2 Methodology

18.3.2.1 Methodology for Functional Requirements Analysis

The safety and power production functions and their success paths, and the operator's role in implementing them, in the System 80+ and the APR1400 are compared to verify their similarity and consistency. The success paths are then compared to the identified allocation criteria to confirm the acceptability of the allocation of control of safety functions in the design.

a. Critical safety functions

   Critical safety functions are physical processes, conditions, or actions relied on to maintain the plant within acceptable design basis limits (e.g., functions that provide reasonable assurance of safe shutdown, maintain plant conditions within safety limits to prevent core melt, and provide reasonable assurance that radiation release does not exceed the limits of 10 CFR 50.34 (Reference 1)).

   These safety functions may be performed by automatic actuation, manual actuation, passive system performance, and/or from inherent feedback as a function of the plant design.

   The APR1400 critical safety functions are provided in the *[FRA/FA Implementation Plan]** (Reference 2).

b. Success paths

Success paths for the critical safety functions have been identified through a high-level functional comparison of the major success paths for the System 80+ plant design and the APR1400 critical safety functions. The APR1400 success paths are provided in the *[FRA/FA Implementation Plan]**.

c. Power production functions

In a similar manner, the functions and success paths are identified for the power production functions for the APR1400.

The FRA also identifies requirements related to:

a. Purpose of the high-level function

b. Conditions indicating that the high-level function is needed

c. Parameters indicating that the high-level function is available

d. Parameters indicating that the high-level function is operating

e. Parameters indicating that the high-level function is achieving its purpose

f. Parameters indicating that the operation of the high-level function can be terminated

18.3.2.2 Methodology for Function Allocation

The operator's role, along with automated systems and passive plant resources, is part of the defense-in-depth approach to provide reasonable assurance that safety functions are maintained. The operator's role in executing safety functions is summarized as follows:

a. Monitor the plant to verify that the safety functions are being accomplished

b. Actuate and control the systems that are not fully automated

c. Intervene when the automatically actuated systems are not operating as intended

Item (a) represents a supervisory role for operators. Item (b) represents manual tasks that the operator is normally expected to perform. Item (c) represents a backup role for operators; it implies the use of automatic, passive, or inherent system resources as a first line of safety defense.

The requirements for determining the allocation of the control of safety functions are provided below.

10 CFR 50

The allocations of critical safety functions are consistent with the mandated allocations of 10 CFR 50, Appendix A, GDC 20; 10 CFR 50.34(f); and 10 CFR 50.62 (Reference 3).

IEEE Std. 603

Without superseding the criteria of 10 CFR 50, the following are additional allocation criteria resulting from the review of the identified requirements from IEEE Std. 603 (Reference 4).

a. Justification for requiring initiation or control of any protective actions solely by manual means, including reasonable assurance of the necessary habitability, are documented.

b. In all other cases, means are provided to automatically initiate and control protective actions and manually initiate all automatic protective actions (at the division level from the control room).

NUREG/CR-3331

Without superseding the criteria of 10 CFR 50 and the criteria resulting from a review of IEEE Std. 603, the additional allocation criteria resulting from a review of

NUREG/CR-3331 (Reference 5) are applied to verify compatibility of the allocated functions with the Style Guide (Reference 6).

18.3.2.3 FRA/FA Implementation

The FRA/FA addresses the issues identified in the OER, the modified functions from plant changes between System 80+ and the APR1400. This evolutionary approach includes the following:

a. Review of requirements applying to the issues of functional design and the allocation of functions to human and/or machine control

b. Description of critical safety functions and success paths in the design

c. Identification of relevant changes from predecessor designs

d. Statement of the operator’s role in executing safety functions

e. Identification of all legally mandated allocations

f. Rationale for assigned allocations

g. Function allocation criteria

18.3.3 Results

The results of the FRA/FA are documented in the Results Summary Report. The report identifies the differences between the APR1400 and System 80+.

18.3.4 Combined License Information

No COL information is required with regard to Section 18.3.

18.3.5 References

1. 10 CFR 50.34, "Contents of applications; technical information."

2. *[KHNP, APR1400-E-J-NR-12001-P, "FRA/FA Implementation Plan," 2013.]**

3. 10 CFR 50.62, "Requirements for reduction of risk from anticipated transients without scram (ATWS) events for light-water-cooled nuclear power plants."

4. IEEE Std. 603-1991, "IEEE Standard Criteria for Safety Systems for Nuclear Power Generating Stations."

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

6. KHNP, APR1400-E-J-NR-12005-P, "Style Guide," September 2013.

18.4 Task Analysis

18.4.1 Objectives and Scope

Task analysis (TA) is an activity of human factors engineering (HFE) that examines task requirements allocated to personnel. The TA is performed according to NUREG-0711 (Reference 1), the *[Human Factors Engineering Program Plan]** (Reference 2), and the *[Task Analysis Implementation Plan]** (Reference 3).

The TA identifies the tasks that are needed to accomplish the functions allocated to personnel and when personnel are required to assume control of automated systems. The TA analyzes the information, controls, and task support requirements needed to perform these tasks.

The completed TA provides the following analytical bases for the HFE design:

a. Identification of the HSI inventory

b. Task allocation requirements for the HSI design, procedure development, and the training program development

c. Workload estimates for the HSI design, staffing, and qualifications

d. Confirmation of the results of the FA

e. Criteria for task support verification as an activity of human factors verification and validation (HF V&V)

The TA is an iterative design activity and becomes progressively more detailed during the design cycle.

The scope includes:

a. Selected representative and important tasks – Plant operation, maintenance, tests, inspections, and surveillance tasks

b. Full range of plant operating modes – Startup, normal operations, abnormal and emergency operations, transient conditions, and low-power and shutdown conditions

c. Important human actions (IHAs) – Human actions resulting from the probabilistic risk assessment (Section 19.1) and the deterministic analysis (Subsection 7.7.2.8 and Subsection 15.0.0.6).

18.4.2 Methodology

The TA includes the following methods:

a. Hierarchical task analysis (HTA) is used to verify information and control requirements (ICRs), HSI inventories, and IHA.

b. Workload analysis is applied to evaluate the operator's workload as a comparison of the time available for the task and the time required to perform the task.

18.4.2.1 Hierarchical Task Analysis

The HTA begins on a gross function level and involves the development of detailed narrative descriptions of operator responsibilities. The analysis defines the nature of the input, process, and output needed from operators.

Input and Design Documentation Review

The APR1400 design documents (e.g., emergency operating guidelines (EOGs)) are reviewed to identify the plant processes, configurations, and modes of operation. In particular, system descriptions and Technical Specifications provide the baseline for analyzing the operational requirements of the HTA.

Hierarchical Task Analysis and Task Decomposition

The HTA, including task decomposition, is a well-known TA method (Reference 4). The HTA produces a hierarchy of operations and provides an effective means of stating how work is organized in order to meet system goals.

The task decomposition is an information-collection method that is used to systematically expand the basic description of the activities that must be undertaken in each task element.

A hierarchical structure is used as the framework to decompose event sequences into components: gross functions, sub-function, task, and task element.

Important Human Actions

IHAs are also analyzed to identify those actions requirements, and findings from the TA are resolved through the formal documentation and issue tracking system per the procedure of the *[Human Factors Engineering Program Plan]**.

Workload Analysis

Workload is evaluated on the basis of comparisons between estimates of time available for and time required by the elements of a task. The resulting fractional use of the available time to perform a task is then compared to the predetermined acceptance criteria. Tasks that have a high percent fractional use of time available are considered for reallocation of the task due to unacceptable high workload situations.

18.4.2.2 Results Documentation

The detail of analysis results is described in the Task Analysis Results Summary Report.

The TA data are stored on a database system to allow manipulation and updating of information. As additions are made to the database, existing portions of the analysis are updated to reflect any changes to the TA to provide reasonable assurance of the internal consistency of the final TA results and consistency with the APR1400 design. When

completed, the TA database incorporates all event sequences specified in Subsection 18.4.1 and the related results from the analysis of those sequences.

18.4.3 Results

The TA results are documented in the Results Summary Report.

The results provide input to the design of HSIs, procedures, personnel training programs, and HF V&V.

18.4.4 Combined License Information

No COL information is required with regard to Section 18.4.

18.4.5 References

1. NUREG-0711, Revision 3, "Human Factors Engineering Program Review Model," U.S. NRC, Washington, DC, November, 2012.

2. *[KHNP, APR1400-E-J-NR-12002-P, "Human Factors Engineering Program Plan," September 2013.]**

3. *[KHNP, APR1400-E-J-NR-12007-P, "Task Analysis Implementation Plan," September 2013.]**

4. B. Kirwan and L.K. Ainsworth, "A Guide to Task Analysis," Taylor and Francis, Washington D.C., 1992.

18.5 Staffing and Qualifications

18.5.1 Objectives and Scope

The objective of staffing and qualifications is to determine the number and necessary qualifications of main control room (MCR) operators for the full range of plant conditions and tasks (i.e., normal, abnormal, and emergency). This section describes the basis for assumption and analysis for the initial staffing and qualifications of operators in the APR1400 MCR.

The determination of the number and qualifications of plant-specific staff in the implementation stage includes consideration of the conditions and constraints from the applicant with the required analyses associated with the other human factors engineering (HFE) elements.

18.5.2 Methodology

The MCR is designed to provide operational flexibility to accommodate a wide range of MCR staffing requirements. The initial staffing level is selected to satisfy the requirements of 10 CFR 50.54 (Reference 1) and applicable guidance in Section 13.1.2 of NUREG-0800 (Reference 2).

This staffing level is to review and validated through the process described in the *[Human Factors Engineering Program Plan]** (Reference 3) and using the methods described in the *[Staffing and Qualifications Implementation Plan]** (Reference 4).

18.5.2.1 Staffing and Qualifications Assumption

As an initial staffing assumption, the shift crew of the MCR consists of five operators: one shift supervisor, one shift technical advisor, one reactor operator, one turbine operator, and one electric operator. The number of operators and their qualifications are shown in Table 18.5-1.

The shift supervisor is a licensed senior reactor operator (SRO) and plays a supervisory role for plant operation for the duration of the shift.

The shift technical advisor is also a licensed SRO and advises the shift supervisor mainly on the safety of the operation. The shift technical advisor may act as a shift supervisor for tasks that are delegated by the shift supervisor.

The reactor operator is a licensed reactor operator (RO) and is responsible for operation of the primary side of the nuclear power plant, including the reactor and safety resources.

The turbine operator is a licensed RO and is responsible for operation of the secondary side of the nuclear power plant including the feedwater system, steam system, turbine generator, condenser system, and instrument air systems. The operator has a function as an assistant operator during the RO's breaks.

The electric operator is a non-licensed operator and is responsible for operation of the electric systems including emergency diesel generators.

The COL applicant is to analyze final plant staffing and required qualifications of the staff (COL 18.5(1)).

18.5.2.2 Staffing and Qualifications Analysis

The initial staffing and qualifications assumption has been applied and demonstrated through the HFE program elements as follows:

a. Task analysis

b. Treatment of IHAs

c. HSI design

d. Human factors V&V

18.5.3 Results

The results of staffing and qualifications activities are documented in the Results Summary Report.

18.5.4 Combined License Information

COL 18.5(1) The COL applicant is to analyze final plant staffing and required qualifications of the staff.

18.5.5 References

1. 10 CFR 50.54, "Conditions of Licenses," U.S. NRC, Washington, DC.

2. NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," Section 13.1.2 "Operating Organization," March 2007.

3. *[KHNP, APR1400-E-J-NR-12002-P, "Human Factors Engineering Program Plan," September 2013.]**

4. *[KHNP, APR1400-K-J-NR-13001-P, "Staffing and Qualifications Implementation Plan," September 2013.]**

Table 18.5-1

Staffing and Qualification Assumptions for the APR1400 MCR

Title	Number of Operator	Qualification
Shift supervisor	1	Senior reactor operator
Shift technical advisor	1	Senior reactor operator
Reactor operator	1	Reactor operator
Turbine operator	1	Reactor operator
Electric operator	1	None

18.6 Treatment of Important Human Actions

18.6.1 Objectives and Scope

The identification of important human actions (IHAs) is based on a combination of probabilistic insights from the probabilistic risk assessment / human reliability analysis (PRA/HRA) and deterministic insights from Chapters 7 and 15. IHAs are integrated into the human factors engineering (HFE) program and the human-system interface (HSI) design process so that personnel errors are minimized and their detection and recovery capabilities are enhanced.

The objective of the treatment of IHAs is to document how the HFE program integrates the results of PRA and deterministic engineering analysis to develop the HFE design.

The scope of integrating IHAs into the HFE design includes risk-important human actions (RIHAs) identified by the HRA, credited manual actions from the transient and accident analysis, and the results of the diversity and defense-in-depth (D3) analysis of the instrumentation and control design process (Reference 1). IHAs are addressed in the function allocation (FA), task analysis (TA), HSI design, procedure development, and training program development to ensure that the design supports IHAs to minimize human error and to enhance detection and recovery capability.

18.6.2 Methodology

The IHA integration into other HFE programs is implemented by the following activities:

a. Identification of IHAs

   The list of IHAs is developed from the analysis results of Subsection 7.7.2.8, Subsection 15.0.0.6, and Section 19.1.

   RIHAs are those that have a significant impact on plant risk. These actions are identified from the Level 1 and Level 2 PRAs for internal and external events of all operating modes. The actions are developed using more than one importance measure and an HRA sensitivity analysis 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.

Deterministically IHAs are identified from Subsection 7.7.2.8 and Subsection 15.0.0.6.

The RIHAs and the resulting list of deterministic HAs are combined into one list of IHAs that are them applied to the HFE program.

b. Interactions with other HFE program elements for the HFE design

   Results of the IHA identification are provided for FA, TA, HSI design, procedure development, and training program development.

c. Interactions with the human factors verification and validation

   HRA performance assumptions such as decision-making and diagnosis strategies in dominant sequences are validated during integrated system validation period using the APR1400 simulator.

Detail method and implementation process are described in the *[Treatment of Important Human Actions Implementation Plan]** (Reference 2).

18.6.3 Results

The results of the treatment of IHAs are documented in the Results Summary Report and include the IHA list, a description of how the IHAs were incorporated into the HFE program, and how the final HSI design is responsive to each IHA.

18.6.4 Combined License Information

No COL information is required with regard to Section 18.6.

18.6.5 References

1. NUREG-0711, Revision 3, "Human Factors Engineering Program Review Model," U.S. NRC, November 2012.

2. *[KHNP, APR1400-E-J-NR-13003-P, "Treatment of Important Human Actions Implementation Plan," September 2013.]**

18.7 Human-System Interface Design

18.7.1 Objectives and Scope

The objective of this section is to describe the APR1400 human-system interface (HSI) design process, including the translation of function and task requirements into the HSI design process through the systematic application of human factors engineering (HFE) principles and criteria.

The scope of HSI design includes the main control room (MCR), remote shutdown room (RSR), technical support center (TSC), emergency operations facility (EOF), local control stations (LCSs) associated with important human actions (IHAs), and the HSI resources. The MCR design includes operator consoles, safety console, and large display panel (LDP).

HSI resources are controls, alarms, information display hierarchy, LDP, and procedure display. The computer-based procedures (CBPs), critical function monitoring (CFM), success path monitoring, accident monitoring instrumentation, and bypassed and inoperable status indication (BISI) are implemented in the HSI resources in integrated fashion.

18.7.2 Methodology

The HFE elements described in Sections 18.2, 18.3, 18.4, 18.5, and 18.6 are inputs to the HSI design process. The Style Guide (Reference 1) has been developed for each HSI resource to facilitate the standard and consistent application of HFE principles to the design.

Issues related to the detailed design of specific aspects of the HSIs are resolved during HSI design tests and evaluations rather than during the human factors verification and validation (HF V&V) phase.

The *[HSI Design Implementation Plan]** (Reference 2) provides a detailed description of the HSI design and the methodology used to develop the design.

18.7.2.1 HSI Design Input

The analyses that are conducted in the early stages of the design process are used to identify HSI requirements. The analyses include the following:

a. Operational experience review – Lessons learned from other complex HSI systems, especially predecessor designs and designs involving similar HSI technology are used as input to the HSI design.

b. Functional requirement analysis and function allocation – HSIs support the operator's role (e.g., appropriate levels of automation and manual control).

c. Task analysis (TA) – Requirements to support the role of personnel are provided by the TA. The TA identifies the following:

   1) Tasks that are necessary to control the plant in a range of operating conditions, from normal through accident conditions

   2) Detailed information and control requirements (ICRs) (e.g., requirements for display range, precision, accuracy, units of measurement)

   3) Task support requirements (e.g., special lighting, ventilation requirements)

   4) IHAs identified through the treatment of IHA

d. Staffing, qualifications, and job analyses – The initial assumptions of staffing, qualifications, and assigned job analyses provide input for the layout of the overall control room and the allocation of controls and displays to individual consoles, panels, and workstations. These assumptions establish the basis for the minimum and maximum number of personnel to be accommodated and requirements for coordinating activities between personnel.

e. System requirements – Constraints imposed by the overall I&C system (e.g., coping with the common-cause failures described in Chapter 7) are significant inputs for the HSI design and are considered throughout the HSI design process.

f. Regulatory and other requirements – Applicable regulatory requirements and industry standards, including those identified in the *[HSI Design Implementation Plan]**.

18.7.2.2 Concept of Operations

The concept of operations considers the following items and is developed and used during the HSI design process:

a. Crew composition

b. Roles and responsibilities of individual crew members

c. Personnel interaction with plant automation

d. Use of control room resources by crew members

e. Coordination of crew member activities

The detailed concept of operations is described in the *[HSI Design Implementation Plan]**.

18.7.2.3 Functional Requirements Specification

During the design process, functional requirements including concept of operation and system functions are established for HSI resources such as alarms, displays, and controls.

The basic functional requirements for HSI resources are described in the *[HSI Design Implementation Plan]**.

18.7.2.4 HSI Concept Design

During the APR1400 HSI concept design development, the HSI designs used in other advanced reactor plants including System 80+, French N4, and Japanese APWR are surveyed and reviewed to establish the MCR design concept.

The requirements of the Electric Power Research Institute (EPRI) Utility Requirements Document (Reference 3) and technical trends of nuclear power plant advanced control rooms of foreign nuclear plants indicated the need for the transition toward a redundant compact operator console type of control room design.

From this design concept, HSI resources, their basic characteristics, and an initial MCR layout are identified.

The control room design has the following resources:

a. Large display panel (LDP)

b. Integrated alarm system

c. Visual display unit (VDU) based information display

d. Computer-based procedure (CBP)

e. Soft control

f. Safety console

These control room resources are reflected in the preliminary design that defines how the HSI supports operator performance. Evaluations and analyses with the use of the simulator and similar plant operators provide inputs in determining the adequacy of the conceptual HSI design.

18.7.2.5 HSI Detailed Design and Integration

The Style Guide contains the HSI resources to facilitate the standard and consistent application of HFE principles to the design. The Style Guide contains the standards and conventions that are produced by tailoring generic HFE guidance to the design of the HSI and defines how the HFE principles are applied. The HFE guidelines in NUREG-0700 (Reference 4) are included in the Style Guide.

The Style Guide is also used to develop a checklist for HFE design tests and evaluations.

A design specification and a detail design (e.g., display, alarm-processing algorithm) will be produced for each HSI resource as a product of the detail design process. The design specification is documented to develop the particular display or algorithm including the functional and task requirements.

Overview of HSI Design and Key HSI Resources

The monitoring and control resources used in the HSI and their major characteristics are described as follows:

Large Display Panel

a. The LDP is legible not only from the operator consoles but also from the probable locations of observers or support personnel in the MCR.

b. Selected parameters and a status that represent the critical safety functions (CSF) and their success paths are provided in a fixed location.

c. Plant-level alarms that indicate the performance of the CSF are provided in the CFM alarm tiles.

d. CFM alarms are integrated with the emergency operating procedure deployment.

e. BISI at the system level is provided for a continuous indication of the bypassed and inoperable status of the engineered safety features (ESF) related process system.

f. System-level alarms and component-level alarms of high priority are provided.

g. Operators can display any format that is available at information displays on the variable display area.

Console Information Display Hierarchy

a. The console information display is an integrated presentation of the plant process information. The operator console information display provides access to displays incorporating system and component status, process parameters, and alarm status and acknowledgement.

b. The information display permits selectable access to any display page in the same VDU.

c. The console information display permits selection of display pages in other VDUs within the same operator console.

d. The console information display permits selection of component controllers or process controllers at the associated soft control display.

e. The console information display permits acknowledgement of alarms.

f. The console information display can be displayed in the variable area of the LDP.

g. The safety parameter display system (SPDS) display pages that are integrated in the operator console information display.

Soft Control Display

a. Soft control is used to control the system and components of the component control system, power control system, and turbine-generator control system.

b. Soft control provides both continuous process control and discrete component control.

c. Soft control permits the selection of operating modes, control signals, and setpoints.

d. Soft control provides continuous displays of all related information being controlled.

Alarms

a. An alarm list grouped by priority is provided in the operator console information display.

b. An alarm list grouped by time of occurrence is provided in the operator console information display.

c. Alarm acknowledgement is possible either at the information display in operator consoles or at the qualified indication and alarm system-non-safety (QIAS-N) displays in the safety console.

d. Alarms are presented in one of the following three states: new, existing, or cleared.

e. Alarms are prioritized and presented so that operator responses can be made based on importance or urgency.

f. The alarm system is designed to minimize the number of alarms using alarm reduction methods.

g. The alarm processing and control at information processing system (IPS) is diverse and independent of that of the QIAS-N.

Computer-Based Procedure Display

a. The CBP provides an overview pane where the current operation step as well as past and future steps of the procedure are presented.

b. The CBP provides detailed instructions of the current step.

c. The CBP provides an integrated presentation of process information and the instructions.

d. The CBP supports the concurrent execution of multiple procedures.

e. The CBP supports retrieving procedures.

f. The CBP facilitates cross referencing other procedures or other steps within the procedure.

g. The CBP keeps track of the step execution status.

h. The CBP monitors the conditions related to the continuously applied steps.

Hard copy procedures, which are used when the CBP is not available, are consistent with the displays.

The *[HSI Design Implementation Plan]** describes the overall HSI design concept and rationale for key resources of the HSI design such as information display, soft controls, computer-based procedure, alarm processing, and control room layout.

<u>Safety Aspects of the HSI</u>

The safety aspects of the HSI are as follows:

a. Safety function monitoring (e.g., safety parameter display system)

b. Periodic testing of protection system actuation functions

c. Bypassed and inoperable status indication for plant safety systems

d. Manual initiation of protective actions

e. Instrumentation required to assess plant and environmental conditions during and following an accident

f. Setpoints for safety instrumentation

g. HSIs for the emergency response facilities (TSC and EOF, where TSC and EOF use identical technologies)

Minimum Inventory Control

The minimum inventory controls are fixed-position controls that include the manual ESF system level actuation switches and component controls required during emergency operating procedures (EOPs) execution. The manual ESF system level actuation switches are provided to execute ESF system actuation. Four channels of switches are provided at the safety console.

Manual reactor trip switches are also included in the minimum inventory controls.

Minimum inventory controls provide defense against operator console failure.

The minimum inventory controls are selected from the results of TA to identify all controls necessary to perform the tasks required for EOP execution.

The *[HSI Design Implementation Plan]** describes the minimum inventory of HSIs.

HSI Change Process

During the design process, all changes are controlled through the Korea Hydro & Nuclear Power Co., Ltd. (KHNP) Quality Assurance Program Description for the APR1400 Design Certification (Reference 5) and are under the *[Human Factors Engineering Program Plan]** (Reference 6).

The Style Guide is updated to address HSI modifications and maintain consistency in the design across the HSIs.

18.7.2.6 HSI Tests and Evaluations

Testing and evaluation of HSI designs are conducted throughout the HSI design development process and are performed iteratively. The methodology used for testing and evaluation is described in the *[HSI Design Implementation Plan]**.

The simulator for integrated system validation is constructed and the methodology including test beds, performance measures and criteria, study participants, test design, and data analysis is developed for HSI tests and evaluations to identify problems and find resolutions that are not readily achieved without simulating operation scenarios. The simulator is used for resolving problems that are found through the evaluations.

The simulator is used to identify human performance issues (e.g., high workload) by running scenarios with operators. The simulator is also used to examine and verify physical layout aspects such as the availability of workspace, physical access, visibility, and related anthropometric issues. Walk-through exercises are performed in the simulator to examine issues such as staffing levels and procedure usage.

18.7.3 Results

The results of the HSI design are documented in the Results Summary Report.

18.7.4 Combined License Information

No COL information is required with regard to Section 18.7.

18.7.5 References

1. KHNP, APR1400-E-J-NR-12005-P, "Style Guide," September 2013.

2. *[KHNP, APR1400-E-J-NR-12008-P, "HSI Design Implementation Plan," September 2013.]**

3. EPRI Utility Requirement Document, Vol. II. Chapter 10, Revision 10, "Man-Machine Interface Systems," 2008.

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

5. KHNP, APR1400-K-Q-TR-11005-N, "KHNP Quality Assurance Program Description for APR1400 Design Certification," September 2011.

6. *[KHNP, APR1400-E-J-NR-12002-P, "Human Factors Engineering Program Plan," September 2013.]**

18.8 Procedure Development

18.8.1 Objective and Scope

The objective of this section is to apply human factors engineering (HFE) process and principles to develop plant procedures that are technically accurate, understandable, easy to use, and validated. The development plan and scope of procedures are described in Section 13.5.

18.8.2 Methodology

The scope and contents of the APR1400 plant operating procedures are addressed in Section 13.5.

The following human factors (HF) aspects are considered during the procedures development as described in Section 9.4 of NUREG-0711 (Reference 1):

a. Task analysis results

b. Important human actions treated in the HSI design

18.8.3 Results

No results are required for this section.

18.8.4 Combined License Information

No COL information is required with regard to Section 18.8.

18.8.5 References

1. NUREG-0711, Revision 3, "Human Factors Engineering Program Review Model," U.S. NRC, November 2012.

18.9 Training Program Development

18.9.1 Objective and Scope

The objective of this section is to apply human factors (HF) aspects systematically during the development of the plant personnel training program. The approach described in this section is consistent with the information in Section 13.2.

18.9.2 Methodology

The approach to training program development follows the applicable guidance and requirements in 10 CFR 55.4 (Reference 1), 10 CFR 52.78 (Reference 2), 10 CFR 50.120 (Reference 3), and NUREG-0711 (Reference 4). The approach includes the five elements related to training program development: (1) organization of training, (2) learning objectives, (3) content of the training program, (4) evaluation and modification of training, and (5) periodic retraining as described in Section 10.4 of NUREG-0711.

The first element, organization of training, identifies the roles of all organizations, particularly applicant and vendor roles, regarding the development of training requirements, training information sources, and training materials and implementation of the training program. This element also describes the qualifications of organizations and personnel involved in the development and conduct of training. Facilities and resources that satisfy applicable requirements and guidance for training simulators are included in the organization of the training, provided in ANSI/ANS-3.5 (Reference 5).

The second element, learning objectives, includes the operating license basis and applicable results from the other elements of human factors engineering (HFE) programs. For example, the tasks identified as unusual tasks in the task analysis, such as demanding high workload or special skills, are addressed in the learning objectives.

The third element, content of training program, is related to how the learning objectives are accomplished. This element identifies which methods are used to convey a particular learning objective (e.g., lecture, simulator, on-the-job training). Specific scenario and plant conditions are also identified.

The fourth element, evaluation and modification of training, defines the methods of evaluating the effectiveness of the training program and trainee mastery of training objectives. Evaluation methods and criteria for training objectives are developed in this element. Procedures for refining and updating the content and conduct of training are also established.

The fifth element, periodic retraining, addresses the plan for how personnel are retrained periodically to maintain their skill level. If any change in the plant occurs, appropriate changes or increases in the retraining will be developed.

18.9.3 Results

No results are required for this section.

18.9.4 Combined License Information

No COL information is required with regard to Section 18.9.

18.9.5 References

1. 10 CFR 55.4, "Definitions," U.S. NRC, Washington, DC.

2. 10 CFR 52.78, "Contents of Applications; Training and Qualification of Nuclear Power Plant Personnel," U.S. NRC, Washington, DC.

3. 10 CFR 50.120, "Training and Qualification of Nuclear Power Plant Personnel," U.S. NRC, Washington, DC.

4. NUREG-0711, Revision 3, "Human Factors Engineering Program Review Model," U.S. NRC, November 2012.

5. ANSI/ANS-3.5-2009, "Nuclear Power Plant Simulators for Use in Operator Training and Examination."

18.10 Human Factors Verification and Validation

18.10.1 Objectives and Scope

The human factors verification and validation (HF V&V) is performed to confirm that the human-system interface (HSI) design conforms to human factors engineering (HFE) design principles and that it enables plant personnel to successfully perform tasks to achieve plant safety and other operational goals.

The HF V&V of the HSI design demonstrates operator task performance capabilities and the capabilities to perform operator functions. All HF V&V activities are performed according to the *[HF V&V Implementation Plan]** (Reference 1).

The Implementation Plan applies to all HSIs in the main control room (MCR), remote shutdown room (RSR), technical support center (TSC), and emergency operations facility (EOF). It also includes the HSIs on local control stations (LCSs) associated with the important human actions (IHAs).

The HF V&V consists of the following six steps: (1) sampling of operational conditions, (2) HSI inventory and characterization, (3) HSI task support verification, (4) HFE design verification, and (5) integrated system validation (ISV), and (6) human engineering discrepancy (HED) resulting from V&V resolution.

The first step, sampling of operational conditions, identifies the conditions that (1) are representative of the range of events that could be encountered during the plant's operation, (2) reflect the characteristics expected to contribute to variations in the system's performance, and (3) consider the safety significance of HSIs.

The second step, HSI inventory and characterization, is performed to accurately describe all HSI displays, controls, and related equipment within the scope as defined by the sampling of operational conditions.

The third step, HSI task support verification, verifies that the HSI provides the needed alarms, information, controls, and task support defined by task analysis (TA) for personnel to perform their tasks as identified by the HSI inventory resulting from the TA.

The fourth step, HFE design verification, verifies that the HSI designs conform to the Style Guide (Reference 2).

The fifth step, ISV and HED resulting from V&V resolution, validates that the integrated system design (i.e., hardware, software, procedures, and personnel elements) supports the safe operation of the plant.

The sixth step, HED resolution (1) documents, tracks, and evaluates HEDs to determine whether they require corrections, (2) identifies design solutions to address HEDs that require correction, and (3) verifies the completed implementation of the HED design solutions.

18.10.2 Methodology

18.10.2.1 Sampling of Operational Conditions

Sampling of operational conditions identifies the range of operational conditions for implementation in all HF V&V activities.

The purpose of sampling operational conditions is to select representative operational conditions that may occur during the lifetime of the plant and to reflect the characteristics (including the HSI) that may affect system performance. The sampling supports determination of adequacy of the task scope for V&V of the three types of human engineering activities: HSI task support verification, HFE design verification, and integrated system validation.

A multidimensional sampling strategy is therefore adopted (Reference 1).

The multidimensional sampling strategy includes:

a. Plant conditions including normal operations, abnormal operations, and transients and accident conditions

b. Personnel tasks including IHAs, results from the operating experience review (OER), manual activation of protective actions, monitoring of automated systems,

procedure-guided tasks, knowledge-based tasks, cognitive activities, and team interactions

c. Situational factors known to challenge human performance including high workload, varying workload, fatigue, and environmental factors

V&V scenarios are defined based on the sampling strategy and the operational conditions (Reference 3).

Portions of the operational conditions are excluded when operators are expected to demonstrate high performance in carrying out the tasks, when tasks are relatively easy to perform, and when operators are expected have a high degree of familiarity with the tasks as a result of continuous training.

Scenarios are defined in accordance with the following:

a. The scenario is designed to be operated in sequence.

b. Scenarios is designed to have a different sequence (e.g., if the sequence of one scenario is “normal-abnormal-emergency-safe shutdown,” the sequence of another scenario may be “normal-emergency- function recovery”).

c. A sequence includes, at a minimum, plant normal and abnormal operating modes including malfunctions. Malfunctions are designed to take place in the first part of the sequence and the scenario includes the tasks that are required of each operator, as well as the operation of safety components.

d. The test scenario is designed to enable participants to operate various systems and components of the plant systems.

e. The events and accidents that are required to operate a number of controls are included in the scenario.

f. Each scenario includes an accident to evaluate the task performance of each member of a crew team.

g. Scenarios are designed to generate a single alarm and also a number of simultaneous alarms.

h. Multiple accidents are designed to be difficult for operators to comprehend the event sequence.

i. Accident scenarios are designed to be controlled by safety systems.

j. Plant control tasks are designed to call up many displays of the primary and secondary systems through the information flat panel display (FPD).

k. When a number of alarms occur simultaneously, they are designed to include various types of alarms, including priority 1, 2, and 3 alarms.

l. Plant monitoring tasks are designed to call up many displays of the primary and secondary systems through the information FPD.

m. Each test scenario includes tasks involving the operation of soft controls such as on/off, start/stop, set point control, and auto/manual mode selection.

n. A number of control tasks that are subject to urgent action in a timely manner are included in the scenarios.

o. Tasks that involve the operation of a group control within a limited time frame are included in the scenarios.

p. Tasks requiring a sequence of control for two or more systems and components are included in the scenarios.

q. Soft control tasks are balanced between safety and non-safety systems to access the information FPD and soft control displays in a repetitive manner.

r. All test scenarios include an emergency operating sequence.

s. The scenarios include an accident or postulated accident that are necessary to be able to evaluate IHAs.

t. Scenarios are designed to be completed between 1 and 3 hours.

18.10.2.2 Design Verification

Design verification is a method that is used to determine that the design meets task and human requirements. Verification activities require a characterization of the HSI.

Design verification is performed in accordance with the review criteria of NUREG-0711 (Reference 4). The design verification criteria are described in the *[HF V&V Implementation Plan]**.

Design verification consists of the following activities:

a. HSI inventory and characterization – Description of all HSI displays, controls, and related equipment within the scope defined by sampling of operational conditions

b. HSI task support verification – Evaluation of whether the designed HSI provides all alarms, information, and control capabilities required for personnel tasks

c. HFE design verification – Evaluation of whether the characteristics of the HSI and the environment in which it is used conform to the Style Guide.

HSI Inventory and Characterization

The objective of the HSI inventory and characterization is to identify the HSI inventory and characterizations required to operate the power plant and to provide input to the HSI task support verification and HFE design verification. In order to achieve this objective, various design documents are analyzed, and the results are compared with the HSI final design content.

The scope of the HSI inventory and characterization is to identify all HSI inventory and characterizations necessary for plant operation within the operational conditions that were

selected for sampling. The HSI inventory and characterization includes information relevant to using the HSI resources and the navigational method of searching for interface information.

HSI Task Support Verification

The purpose of the HSI task support verification is to verify task-support items identified in the TA conducted on the selected operational conditions. The purpose is also to verify that all HSI that are needed to carry out the operator tasks are provided in the HSI design. The HSI task support verification includes input data from the HSI inventory and characterization and task-support items identified in the TA.

HSI task support verification items are collected from the HSI inventory and characterization among the selected operational conditions and the task-support items (e.g., special and protective cloth, job aids, procedures, reference materials) identified during the TA.

The HSI inventory derived from the TA is provided as input data to the HSI task support verification, which is included in the HSI inventory and characterization.

HFE Design Verification

The HFE design verification uses the Style Guide as acceptance criteria for identifying individual item discrepancies such as inadequate letter sizes or lighting levels. The HED process is used to collect, track, and resolve the HEDs resulting from the design verification.

Integrated System Validation

The purpose of the integrated system validation (ISV) is to provide reasonable assurance that an integrated system design supports the successful accomplishment of the operator's required tasks. The ISV is the final stage of the HF V&V and involves the performance-based evaluation. It is the stage in the HSI design process in which the integrated system (i.e., hardware, software, procedures, and personnel elements) is verified to support the plant's safe operation.

The performance evaluation data include directly observable performance data such as the execution time of operator tasks, frequency of human error, and measurable performance data. The evaluation data also include indirectly measurable performance data such as operator task load, situational awareness, and collaboration between operators. Various performance evaluation techniques are applied to collect and analyze the evaluation data in detail.

The techniques include statistical analytical methods as well as reliable and reasonable human-performance evaluation tools.

In order to provide reasonable assurance of reliability of the ISV results, a third-party review of the analysis results is performed by an independent organization. The validation includes operator interaction with the emergency operating procedures (EOPs) and other operating sequences to meet the following objectives:

a. Operator’s ability to execute tasks required by operating guidance

b. MCR configuration, staffing assumptions, and TA results

c. Time available for credited operator actions based on the safety analysis

d. Allocation of functions and support for operating crew situational awareness

e. Operator communication and team interaction

f. Operation with HSI and I&C equipment failures

g. IHA performance assumptions

Each of the postulated accidents, abnormal operational transients, normal operations including startup and shutdown, system lineups, and HSI and I&C equipment failures is performed, which physically represents the MCR configuration and dynamically represents the operational characteristics and responses of the design.

Performance Measures

The performance characteristic assessed in the ISV is multidimensional rather than single dimensional (i.e., single variable). Therefore, ISV performance measurements apply a hierarchical set of performance measures to take the multidimensionality into account by including multidimensional measures such as plant performance, personnel task performance (i.e., primary task, secondary task, error of omission, and error of commission), situational awareness, workload, anthropometric, and physiological measure.

In order to measure the multidimensional characteristics, a measurement is taken of all ISV scenarios first, and the characteristics are then divided into two categories. The first category includes characteristics that need a comprehensive evaluation such as workload, situational awareness, and physiological characteristics. The second category includes characteristics that will be analyzed individually based on a measurement for each scenario. The second category includes characteristics such as plant performance, personnel task performance, and anthropometric measures.

Success Criteria

Success criteria for performance measures are applied in the evaluation of the acquired data to better understand personnel performance and to assess the breadth of the performance findings across the HSI design. Measured values are differentiated to determine a pass/fail measure or a diagnostic measure. Explicit pass/fail criteria are used in the data analysis to determine the conclusions of the ISV.

The performance measures that are used include:

a. Plant performance measures

b. Primary task measures such as time, subjective reports by observers, and records of errors

c. Secondary task measures

d. Situational awareness measures such as freeze probe techniques, real-time probe techniques, and self-ratings

e. Workload measures, such as subjective measures, based on the National Aeronautics and Space Administration Task Load Index

f. Anthropometric and physiological measures

ISV Conclusions

The objective of the ISV is achieved once the scenario data analysis is complete and all scenarios have passed, relevant performance measures are acceptable, and HEDs generated by the ISV are closed.

18.10.2.3 Human Engineering Discrepancy Resolution

HED resolution is the process of evaluating and resolving issues that are identified in V&V evaluations. HEDs are evaluated in accordance with the *[HF V&V Implementation Plan]**.

The Results Summary Report describes the priority and resolution of HEDs. When HED resolution involves a design change, the report will describe how the change complies with the HF V&V evaluation criteria.

18.10.3 Results

The results of HF V&V are documented in the Results Summary Report.

The report includes HF V&V program staffing and resources; detailed procedures for conducting the HF V&V program; HF V&V program data, analysis, and results; identification and resolution of HEDs; and the major conclusions from these activities along with their bases.

18.10.4 Combined License Information

No COL information is required with regard to Section 18.10.

18.10.5 References

1. *[KHNP, APR1400-E-J-NR-12010-P, "HF V&V Implementation Plan," September 2013.]**

2. KHNP, APR1400-E-J-NR-12005-P, "Style Guide," September 2013.

3. KHNP, APR1400-E-J-NR-13002-P, "HF V&V Scenarios," September 2013.

4. NUREG-0711, Revision 3, "Human Factors Engineering Program Review Model," U.S. Nuclear Regulatory Commission, November 2012.

18.11 Design Implementation

18.11.1 Objectives and Scope

The two objectives of the design implementation element of the human factors engineering (HFE) program are (1) to confirm that the as-built human-system interface (HSI) system design is the same as the final verified HSI and (2) to assure that any changes to the finally verified design done by proper HFE change process.

18.11.2 Methodology

The final (as-built) HSIs, procedures, and training are compared with the detailed design description to verify that they conform to the design that resulted from the HFE design process and HF V&V activities before fuel loading.

Design implementation activity consists of:

a. Verifying aspects of the design that were not addressed in V&V

b. Comparing the as-built HSI design and the approved and validated design documents

c. Verifying that all HEDs and all the important HA are satisfactorily addressed

Detail method of design implementation is described in the *[Design Implementation Plan]** (Reference 1).

18.11.3 Results

The results of design implementation is described in the Results Summary Report.

18.11.4 Combined License Information

No COL information is required with regard to Section 18.11.

18.11.5 References

1. *[KHNP, APR1400-K-J-NR-13002-P, "Design Implementation Plan," September 2013.]**

18.12 Human Performance Monitoring

18.12.1 Objectives and Scope

The objective of human performance monitoring is to provide reasonable assurance that operator performance using as-built human system interfaces (HSIs) are maintained throughout the life of the plant as described in Section 13.2 of NUREG-0711 (Reference 1).

The scope of the human performance monitoring program is the performance of plant personnel using HSI designs, the performance changes from an HSI upgrade, the performance of important human actions (IHAs), and the performance that is measured during the integrated system validation (ISV).

18.12.2 Methodology

One of the human performance measures is the number of human errors that result in a reactor trip or generator trip. Another measure is the number of human errors that are collected through a plant's corrective actions program (CAP) and human performance enhancement system.

The objectives of the methodology are as follows:

a. Human actions are monitored commensurate with their safety importance.

b. Feedback information and corrective actions are accomplished in a timely manner.

c. Degradation in performance can be detected and corrected before plant safety is compromised (e.g., by use of the plant simulator during periodic training exercises).

d. Available information that most closely approximates performance data in actual conditions is used when plant or personnel performance under actual design conditions is not readily measurable.

Detail method of human performance monitoring is described in the *[Human Performance Monitoring Implementation Plan]** (Reference 2).

18.12.3 Results

The results of the human performance monitoring are documented in the Results Summary Report.

Human performance issues are identified and corrected under the plant's quality assurance program and CAP.

18.12.4 Combined License Information

No COL information is required with regard to Section 18.12.

18.12.5 References

1. NUREG-0711, Revision 3, "Human Factors Engineering Program Review Model," U.S. NRC, November 2012.

2. *[KHNP, APR1400-K-J-NR-13003-P, "Human Performance Monitoring Implementation Plan," September 2013.]**