April 26, 2023

TP-LIC-LET-0069
Project Number 99902100

U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
ATTN: Document Control Desk

Subject: TerraPower Human Factors Engineering Program Plan and Methodologies Topical Report

This letter provides the TerraPower, LLC Topical Report, “Human Factors Engineering Program Plan and Methodologies.” The full report contains proprietary information and as such, it is requested that Enclosure 3 be withheld from public disclosure in accordance with 10 CFR 2.390, “Public inspections, exemptions, requests for withholding.”

Enclosure 1 is an affidavit certifying the basis for the request to withhold proprietary content from public disclosure. Enclosure 2 contains the public version of the report with appropriate redactions for proprietary content. Enclosure 3 transmits the entire report, including proprietary content.

TerraPower is requesting a compressed review of this Topical Report. This letter and enclosures make no new or revised regulatory commitments.

If you have any questions regarding this submittal, please contact Ryan Sprengel at rsprengel@terrapower.com or (425) 324-2888.

Sincerely,

Ryan Sprengel

Ryan Sprengel
Director of Licensing
TerraPower, LLC

Enclosures: 1. TerraPower, LLC Affidavit and Request for Withholding from Public Disclosure (10 CFR 2.390(a)(4))

2. “Human Factors Engineering Project Plan and Methodologies” Topical Report – Non-Proprietary (Public)

3. “Human Factors Engineering Project Plan and Methodologies” Topical Report – Proprietary (Non-Public)

cc: Mallecia Sutton, NRC
Andrew Proffitt, NRC
William Jessup, NRC
Nathan Howard, DOE
Jeff Ciocco, DOE

ENCLOSURE 1

TerraPower, LLC Affidavit and Request for Withholding from Public Disclosure (10 CFR 2.390(a)(4))

Enclosure 1
TerraPower, LLC Affidavit and Request for Withholding from Public Disclosure (10 CFR 2.390(a)(4))

I, George Wilson, hereby state:

1. I am the Vice President, Regulatory Affairs and I have been authorized by TerraPower, LLC (TerraPower) to review information sought to be withheld from public disclosure in connection with the development, testing, licensing, and deployment of the Natrium^{TM} reactor and its associated fuel, structures, systems, and components, and to apply for its withholding from public disclosure on behalf of TerraPower.

2. The information sought to be withheld, in its entirety, is contained in Enclosure 3, which accompanies this Affidavit.

3. I am making this request for withholding, and executing this Affidavit as required by 10 CFR 2.390(b)(1).

4. I have personal knowledge of the criteria and procedures utilized by TerraPower in designating information as a trade secret, privileged, or as confidential commercial or financial information that would be protected from public disclosure under 10 CFR 2.390(a)(4).

5. The information contained in Enclosure 3 accompanying this Affidavit contains non-public details of the TerraPower regulatory and developmental strategies intended to support NRC staff review.

6. Pursuant to 10 CFR 2.390(b)(4), the following is furnished for consideration by the Commission in determining whether the information in Enclosure 3 should be withheld:

    a. The information has been held in confidence by TerraPower.

    b. The information is of a type customarily held in confidence by TerraPower and not customarily disclosed to the public. TerraPower has a rational basis for determining the types of information that it customarily holds in confidence and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The application and substance of that system constitute TerraPower policy and provide the rational basis required.

    c. The information is being transmitted to the Commission in confidence and, under the provisions of 10 CFR 2.390, it is received in confidence by the Commission.

    d. This information is not available in public sources.

    e. TerraPower asserts that public disclosure of this non-public information is likely to cause substantial harm to the competitive position of TerraPower, because it would enhance the ability of competitors to provide similar products and services by reducing their expenditure of resources using similar project methods, equipment, testing approach, contractors, or licensing approaches.

I declare under penalty of perjury that the foregoing is true and correct.
Executed on: April 25, 2023

George Wilson

George Wilson
Vice President, Regulatory Affairs
TerraPower, LLC

ENCLOSURE 2

“Human Factors Engineering Project Plan and Methodologies” Topical Report

Non-Proprietary (Public)

Document Title:
Natrium Human Factors Engineering Program Plan and Methodologies

Natrium Document No.: NAT-2965	**Rev. No.:** 0	**Page:** 1 of 198	**Effective Date:** 04/18/2023	**Natrium Safety Class:** N/A
Alternate Document No.: NEDO-33991	**Alt. Rev.:** 1	**Originating Organization:** GE-Hitachi (GEH)		**Quality Level:** QL-1
Export Controlled: No	**Attachments:** None			**Target Quality Level:** QL-1
Open Items: No	**Status:** Released		**Document Type:** RPRT	**Natrium MSL #:** HFE

Approval

Approval signatures are captured and maintained electronically; See Electronic Approval Records in EDMS.

☐ Supplemental Signature Sheet Attached

SUBJECT TO DOE COOPERATIVE AGREEMENT NO. DE-NE0009054

INFORMATION NOTICE

This is a non-proprietary version of NAT-2965 Revision 0, which has the proprietary information removed. Portions of the document that have been removed are indicated by an open and closed bracket as shown here: [[ ]]$^{(a)(4)}$. The superscript notation (a)(4) refers to the enclosed TerraPower affidavit, which provides the basis for the proprietary determination.

Important Notice Regarding Contents of this Report

Please Read Carefully

The design, engineering, and other information contained in this document are furnished in accordance with the ARDP Subrecipient Services Agreement between TerraPower and GEH dated May 24, 2021, which also references the Technology Licensing and Engineering Services Agreement between TerraPower and GEH dated May 24, 2021 (TLSA). Nothing contained in this document shall be construed as changing those agreements.

The GEH information in this document is licensed to TerraPower who may issue sublicenses with restrictions in accordance with the agreements above. The use of such GEH information other than in accordance with the agreements above is not authorized. With respect to any unauthorized use, GEH makes no representation or warranty, express or implied, and assumes no liability as to the completeness, accuracy, or usefulness of the information contained.

REVISION HISTORY

Revision No.	Effective Date	Affected Section(s)	Description of Change(s)
0	04/18/2023	All	Initial Issue.

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Acronyms

Acronym	Definition
3D	Three Dimensional
ANS	American Nuclear Society
ANSI	American National Standards Institute
AOF	Allocation of Function
AOP	Abnormal Operating Procedure
CFR	Code of Federal Regulations
COO	Concept of Operation
COTS	Commercial-Off-The-Shelf
DCT	Data Connection Table
DIF	Difficulty, Importance, and Frequency
DRD	Design Requirements Document
EOP	Emergency Operating Procedure
EPRI	Electric Power Research Institute
ESF	Engineered Safety Feature
FOAK	First-of-a-Kind
FRA	Functional Requirements Analysis
GEH	GE-Hitachi Nuclear Energy Americas, LLC
HA	Human Action
HED	Human Engineering Discrepancy
HF	Human Factors
HFE	Human Factors Engineering
HFEITS	Human Factors Engineering Issue Tracking System
HFEPP	Human Factors Engineering Program Plan
HRA	Human Reliability Analysis
HSI	Human-System Interface
I&C	Instrumentation and Control
I/O	Input/Output
IAEA	International Atomic Energy Agency
ID	Identification
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
INL	Idaho National Laboratory
INPO	Institute of Nuclear Power Operations
ISV	Integrated System Validation
NASA-TLX	National Aeronautics and Space Administration – Task Load Index
NCR	Nuclear Island Control Room

Acronym	Definition
NEA	Nuclear Energy Agency
NI	Nuclear Island
NIOSH	National Institute for Occupational Safety and Health
NRC	Nuclear Regulatory Commission
OE	Operating Experience
OER	Operating Experience Review
P&ID	Piping and Instrumentation Diagram
PAM	Post-Accident Monitoring
PDP	Procedure Development Plan
PPA	Procedure Professionals Association
PRA	Probabilistic Risk Assessment
RO	Reactor Operator
RSF	Remote Shutdown Facility
SAMG	Severe Accident Management Guideline
SFR	Sodium-Cooled Fast Reactor
SKA	Skills, Knowledge, and Abilities
SMR	Small Modular Reactor
SRO	Senior Reactor Operator
SSC	Structure, System, and Component
T&E	Testing and Evaluation
TA	Task Analysis
TLSA	Technology Licensing and Engineering Services Agreement between TerraPower and GEH dated May 24, 2021
TPDP	Training Program Development Plan
TSV	Task Support Verification
UIS	User Interface Specification
U.S.	United States
V&V	Verification and Validation
VDU	Video Display Unit

1 INTRODUCTION

This topical report presents information relative to the Natrium^{TM} Human Factors Engineering (HFE) Program Plan (HFEPP)[1].

This topical report describes the HFEPP including related methodologies and is being submitted to the Nuclear Regulatory Commission (NRC) for review and approval. NRC approval facilitates reference to this report in future licensing documentation without requiring additional review of the HFEPP material provided in this report.

The high-level goal of the HFEPP is to specify a proportionate, integrated, and effective Human Factors (HF) program which reduces the risks and consequences influenced by human interactions. This goal is further supported by specific HFE methodologies described in the appendices to this report. Definitions specific to this report are provided in Section 9.

1.1 Purpose

The HFEPP defines the scope of the structures, systems, and components (SSCs) to which HFE technical elements are applied and the approach for determining the level of HF application in these areas, as described in Section 1.2 and Section 3, respectively.

Section 4 defines the role of HF within the project, the interaction among HF and other engineering disciplines, and the flow of work and information within and among each of the following HFE technical elements:

- Operating Experience Review (OER)
- Functional Requirements Analysis (FRA)
- Allocation of Function (AOF)
- Staffing
- Treatment of Important Human Actions (HAs)
- Task Analysis (TA)
- Human-System Interface (HSI) Design
- Procedures
- Training and Qualification
- HF Verification and Validation (V&V)
- Design Implementation
- Human Performance Monitoring

The HFEPP describes each of these HFE technical elements in Section 5, which also defines the way that the general human-centered HFE design goals are operationalized and verified during the design process, through application of the HFE technical elements, tools, and technical guides.

These HFE design goals are as follows:

- Personnel tasks are accomplished within the evaluated time frame and performance criteria

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[1] Natrium is a TerraPower and GE-Hitachi technology.

- Information systems support a high degree of situation awareness of the state of the plant and actions required
- AOF maintains human vigilance and provides acceptable workload levels that minimize periods of human underload and overload
- HSI minimizes error and provides for error detection
- HSI design supports the capability of the operating crew to recover from previous decisions and actions that did not achieve intended results
- Application of ergonomic principles to working areas and their environments ensures these areas are safe and designed for the human to perform operations, maintenance, inspection, surveillance, and test activities

Section 6 describes the processes and procedures that establish the steps taken for effective implementation and the measures that ensure consistency across the work performed for each HFE activity or technical element.

Specific methodologies supporting the HFEPP are described in the following appendices to this topical report:

Appendix A - Human Factors Engineering Allocation of Function and Task Grading Methodology

Appendix B - Human Factors Engineering Task Analysis and Human-System Interface Design Methodology

Appendix C - Human Factors Engineering Staffing Analysis Plan

Appendix D - Human Factors Engineering Verification and Validation Plan

1.2 Scope

The HFEPP applies to Nuclear Island (NI)-related HSIs including those at the following locations:

- NI Control Room (NCR)
- Remote Shutdown Facility (RSF)
- Local controls
- Emergency support facilities

As discussed in Section 3, the application of HFE is graded (or proportionate) based on nuclear safety, personnel safety, and asset protection to apply a higher level of emphasis and rigor for important human interactions that are safety critical or hazardous.

2 REQUIREMENTS AND TECHNICAL BASIS

This section contains the process requirements and technical basis inputs applicable to the creation, implementation, and maintenance of an HFE program. Additional requirement and technical basis input documents for HFE design or specific technical element areas are included in the applicable sections of this document.

The HFEPP creates an HFE program that is compliant with requirements in Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, “Domestic Licensing of Production and Utilization Facilities,” Section 34, “Contents of applications; technical information,” (Reference 1), paragraphs (f)(2)ii and (f)(2)iii.

The HFEPP also considers the relevant good practice provided in Institute of Electrical and Electronics Engineers (IEEE) 1023-2020 (Reference 2), and NUREG-0711 (Reference 3).

3 CRITERIA FOR DETERMINING AREAS OF CONSIDERATION

3.1 Risk Level Determination

A graded (or proportionate) approach to HF is applied to the project and provides focus for analysis and design. The graded approach provides basic HFE attention to human interactions within the system and provides emphasis on important human interactions. The HAs for grading are those functions and tasks allocated to humans in AOF as discussed in Section 5.3. The grading of HAs for the project is based on three risk categories:

- Nuclear Safety
- Personnel Safety
- Asset Protection

As shown in Table 3-1, these risk categories are assessed against criteria that result in a high, medium, or low risk level. [[

]]$^{(a)(4)}$ The overall risk level for the HA is determined by the highest risk level assigned within the three categories.

Table 3-1: Risk Level Assessment Matrix

[[				
				]]$^{(a)(4)}$

[[

]]$^{(a)(4)}$

3.1.1 Nuclear Safety

[[

]]$^{(a)(4)}$

3.1.2 Personnel Safety

[[

]]$^{(a)(4)}$

3.1.3 Asset Protection

[[

]]$^{(a)(4)}$

3.2 Human Factors Engineering Application Level Determination

[[

]]$^{(a)(4)}$

Section 7 contains a matrix of HFE technical element application grading based upon the HFE application level.

The results of the risk level determination and the HFE application level determination are captured in the task grading results, which are discussed in Appendix A. [[
]]$^{(a)(4)}$

3.3 Rationale

It is important to provide support for the human within the system design; however, some human interactions with the systems are more important than others. To provide the appropriate focus for analysis and design, a graded approach to HFE is applied. The graded approach provides HFE attention to human interactions within the scope of the plan and provides emphasis on important human interactions.

The graded approach is based upon relevant approaches in NUREG-1764 (Reference 4) for risk-informed reviews that consider both probabilistic and deterministic considerations. It is also based on recent United Stated (U.S.) industry work on the HFE application detailed in Electric Power Research Institute (EPRI) 3002004310 (Reference 5). These approaches represent industry best practices for risk-informed evaluations and decision making.

4 HUMAN FACTORS ENGINEERING ORGANIZATION

4.1 Roles and Responsibilities

4.1.1 Roles

The HFE team consists of a core team and an extended team dedicated to HFE implementation. The extended team includes members from other disciplines within the engineering design team and is discussed in Section 4.2.

The core HFE team is comprised of an HF technical lead and two general roles: HF engineering and HF operations/maintenance. The HFE team, as an entity, satisfies the professional experience qualifications described in A.2, B.2, and C.2 of this section. The satisfaction of these qualifications associated with a particular skill area may be realized through combining the professional experience of two or more members of the HFE team who individually satisfy other defined credentials of that particular skill area, but who do not possess all of the specified professional experience. The definition of roles is based on NUREG-0711 (Reference 3).

A. Technical Lead

1. Contributions:

    a. Provide technical and program oversight and review. Responsible for ensuring that HF activities, interfaces, and outputs meet HF requirements and align with HFE program objectives

    b. Act as point-of-contact for schedule development, integration, and management

2. Minimum qualifications:
    a. Equivalent to either an HF engineer or HF operations/maintenance role with the following additional qualifications:
        i. HF capability across a breadth of HFE competence areas suitable for the full scope of the HFE program
        ii. Three years project management-related experience, preferably managing HFE or other technical, cross-cutting programs

B. HF Engineer

1. Contributions:
    a. Provide knowledge of human performance capabilities and limitations, applicable HF design and evaluation practices, and HF principles, guidelines, and standards
    b. Develop and perform HF analyses
    c. Participate in the resolution of identified HF problems
2. Minimum qualifications:
    a. Bachelor’s degree in HFE, engineering psychology, or related science
    b. Four years cumulative experience related to the HF aspects of human-computer interfaces. Qualifying experience includes at least the following activities within the context of large-scale human-machine systems (e.g., process control): design, development, and Testing and Evaluation (T&E)
    c. Four years of cumulative experience related to the HF aspects of workplace design. Qualifying experience includes at least two of the following activities: design, development, or T&E

HF engineer sub-specialties include cognitive science, ergonomics, HSI, and testing/experimental design.

C. HF Operations/Maintenance

1. Contributions:
    a. Provide knowledge of operations, maintenance, and testing activities including task characteristics, HSI characteristics, environmental characteristics, and technical requirements related to operational activities
    b. Provide knowledge of operations, maintenance, and testing activities in support of activities, such as development of HSIs, procedures, and training programs
    c. Participate in the development of scenarios for Human Reliability Analysis (HRA) evaluations, TAs, HSI T&E, validation, and other evaluations
    d. Provide knowledge of operations, maintenance, and testing tasks and procedure formats

e. Provide direct plant Operating Experience (OE)

f. Provide input for developing Emergency Operating Procedures (EOPs), procedure aids, and computer-based procedures

g. Develop content and format of personnel training programs and training systems

h. Coordinate training issues arising from HF design activities

2. Minimum Qualifications:

a. Bachelor's degree in a technical field

b. Holds, or has held, a Senior Reactor Operator (SRO) license or equivalent

c. Five or more years of plant operations experience including exposure to plant procedure development, personnel training, and operational nuclear plant programs

d. Two or more years of experience in qualified areas of HF analysis, design, T&E

HF operations/maintenance sub-specialties include OER, operations analysis (FRA, AOF, and TA), alarm design, HRA, procedure development, and training.

4.1.2 Responsibilities

The responsibilities of the HFE team are to establish and perform the activities as defined in this plan ensuring that the facilities, systems, equipment, and tools are designed to be compatible with the capabilities, limitations, and needs of the human. Specifically, the HFE team guides and oversees the design activities, and ensures that the execution and documentation of steps in the activities are carried out in accordance with the established program and procedures.

4.2 Related Groups

Due to the cross-functional nature of an integrated HFE design process, HFE interfaces with other disciplines who act as extended members of the HFE team. The integration of related groups with HFE is formally addressed through an integrated detailed schedule, as discussed in Section 6.1.

The descriptions of the following disciplines and groups, and their contributions to HF, are adapted from NUREG-0711 (Reference 3). The actual engineering design team disciplines may vary, but the scopes described are covered.

A. Mechanical and Electrical System Engineering

1. Provide knowledge of the purpose, operating characteristics, and technical specifications of major plant systems

2. Provide input to HFE analyses, especially function and TAs

3. Participate in developing procedures and scenarios for TA, validation, and other analyses

B. Instrumentation and Control (I&C) Engineering

1. Provide detailed knowledge of the HSI design, including control and display hardware selection, design, functionality, and installation

2. Provide knowledge of information display design, content, and functionality
3. Participate in designing, developing, testing, and evaluating the HSIs
4. Provide knowledge of data processing associated with displays and controls
5. Participate in designing and selecting computer-based equipment, such as controls and displays
6. Participate in developing scenarios for HRA, validation, and other analyses involving failures of the HSI data processing systems

C. Civil/Structural Engineering

1. Provide knowledge of the overall structure of the plant, including performance requirements, design constraints, and design characteristics of the following:
    a. NCR
    b. RSF
    c. Local controls
    d. Emergency support facilities
2. Provide knowledge of plant components configuration
3. Provide input to plant analyses, especially function analysis, TA, and development of scenarios for TA and validation

D. Integrated Plant Engineering

1. Prepare the safety analysis establishing the SSC and HAs that are credited for successful event mitigation
2. Provide knowledge of maintenance, inspection, and surveillance activities, including:
    a. Task characteristics
    b. HSI characteristics
    c. Human performance tenets
    d. Environmental characteristics
    e. Technical requirements related to the conduct of these activities
3. Support the design, development, and evaluation of the control room and other HSIs throughout the plant thereby providing assurance that each can be inspected and maintained to the specified reliability
4. Provide input regarding maintainability and inspectability during the development of procedures and training
5. Participate in the development of scenarios for HSI evaluations including TA, HSI design T&E, and validation

E. Risk and Reliability Engineering

   1. Perform PRA and HRA to quantify the human contribution to risk and inform HF analyses

   2. Provide knowledge of plant component and system reliability and availability and assessment methodologies to the HSI development activities

   3. Participate in the development of scenarios for HSI evaluations, especially validation

   4. Provide input to the design of HSI equipment thereby providing assurance reliability and availability goals during operation and maintenance are maintained

F. Simulation Assisted Engineering

   1. Develop the simulators for HF V&V activities

5 TECHNICAL ELEMENT DESCRIPTIONS AND METHODS

The following sections provide a general overview of each HFE technical element. Figure 5-1 illustrates the relationship among the technical elements. This representation is simplified for clarity. The HFE activities are iterative and progressive, such that results from analysis and activities later in the program, for example staffing analysis or procedure validation, are used for feedback and to refine the AOF, TA, HSI design, and procedure development. Section 7 contains a focused summary regarding how TA, HSI design, procedure development, HFE V&V, and design implementation are graded and applied, using the approach described in Section 3.

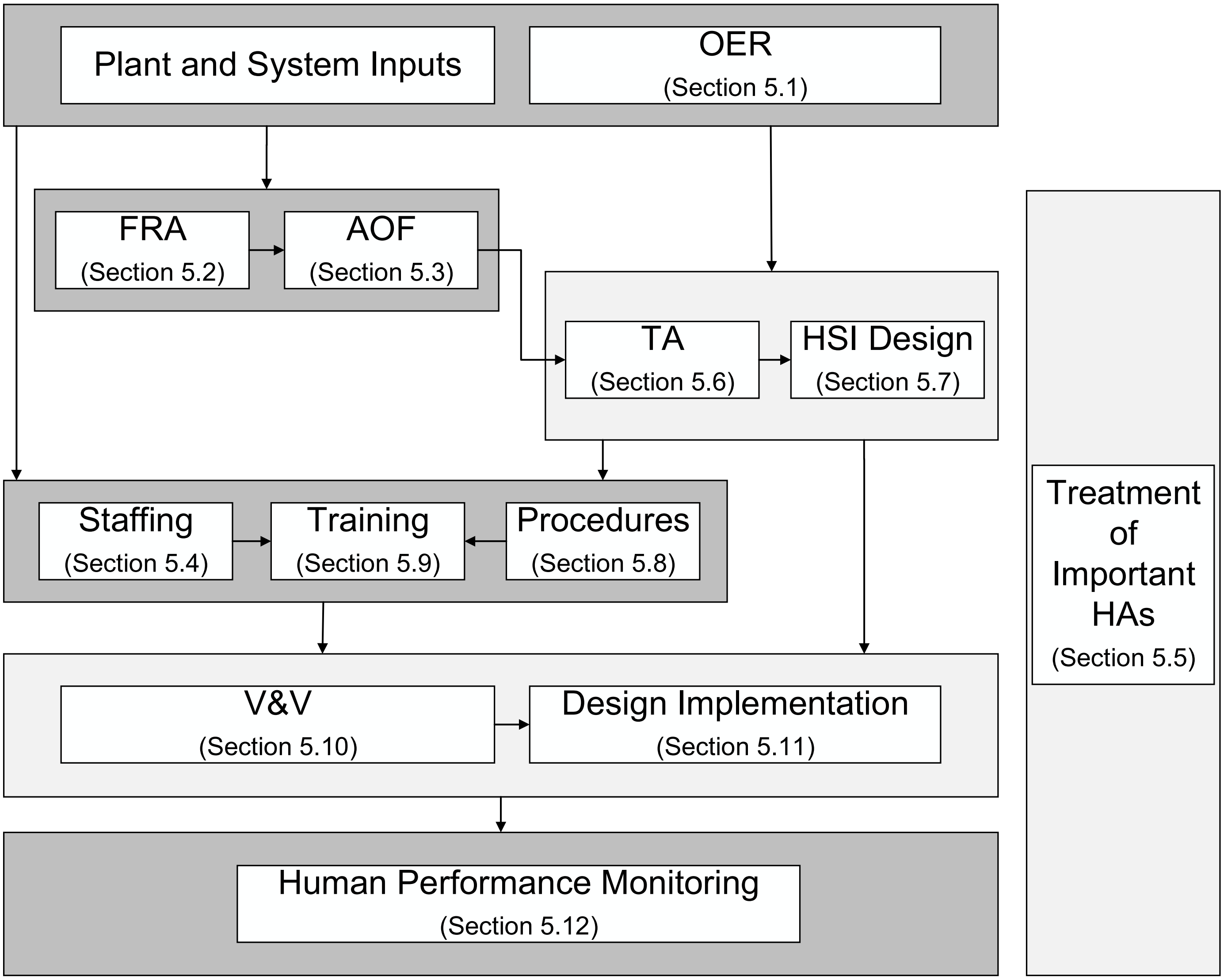

Figure 5-1: Human Factors Engineering Technical Elements Relationship

The HFE technical elements are integrated with the wider plant design processes as discussed in Section 6. The HFE technical elements use the most relevant and proven methods as discussed in the following sections.

5.1 Operating Experience Review

The main purpose of conducting an OER is to identify HFE issues related to plant or personnel safety. The issues and lessons learned from OE provide a basis for improving the plant design in a timely way (i.e., at the beginning of the design process).

For the project, an OER report is developed. The objective is to identify and analyze issues in previous designs that are similar to the current designs. This allows negative features associated with predecessor designs to be avoided and positive features to be retained.

The OER report addresses the following:

- Literature review on any previous deployment of similar reactor technology with an HFE focus
- Personnel interviews or questionnaires on any previous deployment of the same reactor technology with an HFE focus
- OERs related to HSI technology employed to support HAs included in the PRA and safety analysis
- Focused reviews of HAs from predecessor designs that are similar to HAs included in the PRA and safety analysis

Outputs of the OER may influence the design or design processes in each of the other HFE technical elements.

5.2 Functional Requirements Analysis

FRA is performed to define the necessary functions that satisfy the HFE principal design requirements of the plant. These principal design requirements are necessary to meet plant goals and objectives. These goals and objectives include meeting regulatory and customer requirements and are documented in the overall plant design specification.

The FRA is part of the general engineering design approach and part of the requirements management process. The requirements management process for the project consists of the following activities, which apply equally to the requirements, including the functional requirements: elicitation, analysis, allocation, and documentation. The result of this analysis is the definition of system functions that support and are traced to the principal design requirements of the project.

The FRA process determines the functions associated with each system. When the FRA is complete, the framework is set for determining the role of the controllers (whether human or machine) in regulating active (non-passive) functions. The output document eventually contains the full list of functions with detailed characterizations of relevance to HFE, particularly those functions required to perform AOF and inform the TA and HSI Design activities. The functions from the FRA are input to the AOF process described in the next section.

5.3 Allocation of Function

AOF establishes a plant control scheme that enhances plant safety and reliability by taking advantage of human and machine strengths and avoiding human and machine limitations. Further detail is also provided in Appendix A. The allocation arrangement enhances plant performance by specifying overlapping and redundant responsibilities to the human and machine.

The AOF strives to provide personnel with logical, coherent, and meaningful tasks, and establishes a design that maintains human vigilance and situation awareness. The goal of the AOF is to provide acceptable workload levels per job role that minimize periods of human underload and overload. This is done through review of the initial allocation as a whole and using expert judgment to determine if the assigned functions per job role are suitable and sufficient. Further analysis of workload and requirements for situation awareness are then undertaken through downstream activities, such as TA, HSI T&E, and HFE validation (Sections 5.6, 5.7.6, and 5.10, respectively).

The AOF process is based on the relevant good practice methodology presented in IAEA TECDOC-668 (Reference 6). The methodology identifies functions that are not to be assigned to humans due to criteria such as:

- Physical demands (forces, posture)
- Cognitive demands (multitasking, stress)
- Combination of physical and cognitive demands (accuracy, response time)
- Environmental conditions (temperature, radiation)

The AOF process takes additional input for criteria from NUREG/CR-2623 (Reference 7). These are criteria that limit or preclude human participation in a function, and criteria that make human participation mandatory. The criteria for human participation, along with the related criteria in IAEA TECDOC 668 (Reference 6) and INL/EXT-13-30117 (Reference 8), are top-level, overriding criteria in the AOF process.

The AOF process establishes an initial (hypothesized) allocation based on expert judgment from a panel that includes [[ ]]$^{(a)(4)}$. The panel uses OE, as well as information from additional Sodium-Cooled Fast Reactor (SFR) subject matter experts, to determine how similar applications were allocated and evaluate how they have performed.

The function input to the AOF is described in Section 5.2. In addition, with the conversion of functions to tasks, multiple tasks may be necessary to support the function. [[ ]]$^{(a)(4)}$ The support tasks require a task allocation that uses the same criteria applied to the AOF. The PRA also provides input to the AOF, specifying when HAs are modeled to backup automatic (machine) actions.

Output functions from the AOF are initially allocated to human only, machine only, or shared (both human and machine). For machine only allocations, it is necessary to establish backup actions when redundancy is not possible or reasonable. For this case, the allocation category machine-human backup is used. The initial allocation becomes the design and TA starting point. If necessary, the initial AOF is iterated as plant design progresses. The overall plant AOF is evaluated and iterated as part of early integrated testing, if necessary, until a final AOF is established for Integrated System Validation (ISV) testing.

5.4 Staffing

Plant staff and their qualifications are important considerations in the HFE design. A staffing analysis process systematically determines the minimum staff complement for the project. Staffing analysis starts with staffing and shift-work assumptions based on the HFE Concept of Operation (COO). These assumptions allow undertaking the initial TA activities and act as a baseline for the formal staffing analysis activities. The staffing analysis also determines the maximum staffing in collaborative facility spaces such as control rooms for Identification (ID) of maximum occupancy to inform civil and structural determination of room sizes. The assumed staffing is used to analyze the most resource-intensive credible events postulated for all operating states, including normal operations, design basis events, and emergencies, and the assumptions are either validated or corrected.

The confirmed minimum and maximum staff and shift design information is then assessed for any effect on the TA, and then is later assessed and updated further based on the more formal staffing analysis activities. This confirmed job role and complement determination is also an input to training program development, where base qualifications are established, and the training program is designed. Staffing analysis is further confirmed through workload analysis and evaluated using mock-ups, modeling, or simulation, as appropriate, with the HSI T&E described in Section 5.7.6. The staffing design is finalized once it is validated with the ISV, as discussed in Section 5.10.

5.5 Treatment of Important Human Actions

HAs important to safety are determined using both deterministic and probabilistic means from the safety analysis and PRA. [[

]]$^{(a)(4)}$

HRA is conducted by the risk and reliability team and is an integral part of the development of a complete PRA. HRA evaluates the potential for, and mechanisms of, human error that may affect plant safety. The core HFE team presented in Section 4.1 contributes to the HRA by participating in the definition of the task (steps) for the HRA. In addition, the HFE design (TAs, HSIs, procedures, and training) is an input to the definition of performance shaping factors for the HRA.

5.6 Task Analysis

TA is the ID of task requirements to accomplish the functions and tasks allocated in whole, or in part, to humans. These are designated in the AOF results as human only, shared, or machine-human backup.

The TA results in the assignment of tasks to the job positions specified by the staffing process described in Section 5.4. TA is used to determine the steps needed to accomplish HAs and document the task details and required task support (HSI controls, indications, and alarms). [[

]]$^{(a)(4)}$

TA methodology (Appendix B) is developed specifying the systematic process for TA. The TA methodology provides the steps and criteria used for TA. [[
]]$^{(a)(4)}$, the TA methodology specifies that the following information be documented for each task:

- Descriptive narrative of the task
- Cue that determines the need for the task
- Prerequisites for the task
- Time available versus time required to complete

Further information is documented for each step of the task:

- Step sequence
- Action to be taken
- Information needed
- Controls needed
- Alarms needed

- Personnel involved
- Communication needs
- Location and access considerations
- Workspace needed
- Job aids, tools, or equipment needs
- Environmental considerations and potential hazards
- Special or protective clothing needs
- Time available versus time required to complete (if needed on a step basis)

The detailed TA is informed by and coordinated with the HRA when applicable. The results of the detailed TA are used as input to HSI design, procedure development, and training program development. The detailed TA also includes preliminary workload analysis and assessment of requirements for situation awareness.

[[

]]$^{(a)(4)}$ If problems with task support are noted, an HFE issue or Human Engineering Discrepancy (HED) is created to track the issue to resolution and is documented in the HFE Issue Tracking System (HFEITS) (Section 6.4).

Additional forms of TA are used to support the evaluation and design of the HSI used for the [[ ]]$^{(a)(4)}$, link analysis coupled with timeline analysis informs the layout of HSIs to optimize task performance. [[ ]]$^{(a)(4)}$

5.7 Human-System Interface Design

5.7.1 Description

The HSI design process represents the translation of functional and task requirements into HSI characteristics and functions. The HSI includes the regions or points at which a person interacts with SSCs in the control room and the plant. HSI design uses a structured methodology to guide HF engineers in:

- Developing concepts
- Defining requirements
- Developing and supporting detailed design
- Performing T&E

The HSI design process follows good practices provided in IEEE 1289-1998 (Reference 9). A detailed methodology for HSI development and testing is provided within the HSI development process plan (Appendix B).

5.7.2 Human Factors Engineering Concept of Operation

The HSI concept design scope includes development of the HFE COO document, also sometimes referred to as a concept of use document. The HFE COO document describes the ways that users interact with HSIs and with each other to monitor, control, and maintain the plant such that it functions in a safe, secure, regulation-compliant, and efficient manner. The HFE COO acts as a baseline set of assumptions regarding the future operational plant. This includes job design aspects such as the definition of user roles, minimum staffing, expected user population characteristics, anthropometric data, aspects of work coordination relevant to the design, and crew communications.

The HFE COO document also contains the alarm philosophy (which describes the alarm concept and defines basic goals for alarm management including ID, prioritization, and filtering/suppression) and the concept for computer-based procedures (which includes reference to standards, such as IEEE 1786-2022 (Reference 10)). The HFE COO document provides input into the development of the HFE Design Requirements Document (DRD) by defining the user population for whom the design is created.

5.7.3 Human Factors Engineering Control Room Concept

The HFE control room concept contains assumptions regarding HSI technology selections, room layout and spacing, as well as inputs from the HFE COO document. The HFE control room concept contains conceptual drawings of room layouts and workstation configurations. The HFE control room concept defines a design to support the concepts of use and user population, as defined by the HFE COO document. The HFE control room concept helps bound the scope of HSI elements covered by the DRD.

5.7.4 Human Factors Design Requirements Document and Human-System Interface Style Guide

The HSI design process also includes the development and use of HFE design requirements tailored to the unique aspects of design. These define design-specific conventions and ensure standardization and consistent application of HFE principles (similar look and feel across HSI). These HFE design requirements are housed in the document or set of documents known as the HFE DRD. The HFE DRD scope includes requirements for the following areas:

- Workplace design (including environmental)
- Maintainability (including equipment layout for operability and maintenance)
- Access and egress
- Materials handling
- Information display (hardware- and software-based)
- User interface management
- Controls (hardware- and software-based)
- Alarm system
- Safety function and parameter monitoring system
- Group view display system
- Computer-based procedures
- Computerized support system

- Communication system
- Workstation design
- Labels and signs

The HFE DRD and HFE design documents are developed to comply with codes, standards, and HFE best practices, such as NUREG-0700 (Reference 11). The HFE DRD is written to account for variation between target user populations and to avoid conflict with user population conventions and stereotypes, as defined in the HFE COO document.

The initial revision of the HFE DRD is focused on providing HFE requirements that affect building layout, environment, and hardware. The initial revision of the HFE DRD begins by taking input from applicable requirements, codes, and standards as defined in this plan. For the initial HFE DRD revision, document development is in parallel with, and informed by, the OER, the HFE COO, and the HFE control room concept. HFE findings from the OER relating to HSI design are allocated to HFE DRD to provide input identifying positive HSI features to be included and negative HSI features to be avoided. The HFE DRD takes input from the HFE control room concept to contain requirements which are applicable to the selected HSI technology choices. As the design matures and new or different HSI technologies are the subject of optioneering, prototyping, and testing, the HFE control room concept evolves, and the HFE DRD content is updated to contain requirements for the latest HSI concepts and technologies.

The next revision of the HFE DRD contains updates to any existing requirements resulting from OER findings as well as control room concept optioneering. This revision of the HFE DRD also includes the addition of new requirements for software based HSI design and user interaction. This revision is also informed by the HFE COO regarding assumed user population characteristics and coding stereotypes, and the HFE control room concept in regard to expected software-based HSI use and software-based HSI design compatibility and optimization with HSI technology choices (e.g., mouse or touchscreen-based input devices).

The HFE DRD supports a detailed HSI style guide, user interaction scheme, alarm philosophy, information architecture, and navigation, as well as the development of display templates and an HSI element library to support consistent HFE DRD application during HSI detailed design.

The HSI style guide development stage includes agile, iterative HSI usability testing using samples of personnel who are representative of the end users (as defined in the HFE COO) to test, adjust, and solidify HSI concepts, conventions, and technologies. Early HSI T&E includes evaluations and user feedback in areas such as visual coding, font readability, control interaction and feedback, and navigation. Once HSI design concepts are deemed acceptable for the defined user population, these design conventions are confirmed and documented through updating the HSI style guide.

As detailed system design continues, the HSI T&E activity evaluates fidelity as the testing platform and simulation logic are further developed. When fidelity is proven, HSI T&E includes evaluation of workload, situation awareness, crew communications, and task support.

The HSI T&E results feed back into the HSI design at the appropriate level using the HFE issue tracking process (as described in Section 6.4 and Section 8). HFE issue resolution may include adjusting an individual system display design, updating an HSI element in the HSI library, or revising an HFE DRD requirement to address the HFE concern identified in the HFE issue.

5.7.5 Detailed Human-System Interface Design

Detailed HSI design develops the features selected in the basic design process. HFE design requirements contained in the HFE DRD and task support requirements generated by the TA are used to generate detailed HSI designs. Applicability and allocation of the HFE DRD and task support requirements are determined by the HFE team. The detailed design process addresses hardware, software, layout, formatting, and features incorporated into the HSI design to meet human-centered design goals.

Applicable requirements are applied to the developing design and compliance is documented and maintained. Where a requirement cannot be met by the current design, HFE collaborates to develop a design solution or a justification to take exception to an HFE design requirement. When evaluating Commercial-Off-The-Shelf (COTS) products that do not comply with the HFE DRD, special considerations are applied by the HF engineer to determine and document acceptability of the discrepancy. These considerations are:

- Tradeoff of benefits using a proven, standard solution compared to the benefits of a custom solution that more closely meets the HFE DRD requirements
- Analysis of COTS vendor HF design basis and documentation in relation to HFE codes, standards, and relevant good practice
- Evaluation of COTS HSI design applicability to the defined user population, conventions, and stereotypes
- Degree of design and task support integration and consistency among the COTS product and the rest of the overall HSI
- ID of usability or human performance concerns with the proposed application of the COTS product

5.7.6 Human-System Interface Tests and Evaluations

HSI T&E are part of the iterative HSI development process. The HSI T&E follows relevant good practices provided in IEEE 845-1999 (Reference 12). Personnel who are representative of end users (nuclear power plant operators or personnel with plant operations/maintenance experience) evaluate an HSI design concept to show the efficiency and efficacy of the design for the intended population. The purpose of early, smaller-scope usability testing is to find and correct issues immediately rather than waiting for later V&V activities. HSI test and evaluation scope ranges in complexity from simple user questionnaire responses and comments to empirical, performance-based techniques. Any issues that are identified during the HSI development process are entered into the appropriate section of the HFEITS database for tracking, reviewing, and resolution (Section 6.4).

During HSI T&E, it is necessary to employ multiple evaluation tools and testbeds based upon design maturity, HSI features to be tested, and test objectives. This creates efficiency in terms of time and resources and supports design-oriented successive refinement.

Evaluation tools may include the following:

Drawings

Paper-based and software-based drawings are used to perform preliminary user checks to ensure design assumptions or design concepts are viable. Drawings are presented to gain user feedback on design change concepts as the project progresses.

Three Dimensional Mock-Ups

Mock-ups are constructed and used as tools in the development of the HSI to evaluate the system design before the actual manufacture of system hardware. Mock-ups provide a basis to resolve access, workspace, and related human engineering issues and incorporate the solutions into HSI design. Mock-ups are physical or virtual.

Physical mock-ups are used to illustrate and evaluate proposed HSI hard switch, indication layouts, and positioning using walk-through/talk-throughs. Additional fidelity may be added to a physical mock-up through the inclusion of interactive Video Display Units (VDUs). VDUs allow users to sit at the display and interact with software-based controls and indications within the context of the control area.

Three Dimensional (3D) virtual mock-ups may be used to make ergonomic assessments of general console and panel shape. Software-based 3D models are used for designing and testing room layouts with revision management for tracking design iterations. HSI designers use 3D technology to rapidly prototype and test designs against ergonomic requirements and recommendations. For ergonomic evaluations, 3D human models are used to represent the upper and lower bounds for target user population anthropometric measurements. Human models can be used within the proposed design to evaluate sightlines, reach, and access.

Simulation

A generic plant simulation model may be used by the HFE team for HSI development and usability testing. Once a site-specific system model becomes available, tests and evaluations are conducted using site-specific models. Dynamic simulation is used as an HF design tool for HF validation testing and for training. Simulation is run with user interface through a computer-based VDU workstation, a glass-top simulator (virtual controls and indications), or a hardware-based simulator (physical controls and indications).

5.7.7 Graded Application of Human Factors During Human-System Interface Design

The HSI design products are created through the interaction and coordination of the HFE team and discipline engineers. The degree and type of interaction is based on the risk-based HFE application level discussed in Section 3 and Section 7.

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5.7.8 Human Factors Human-System Interface Design Output

The output of the HSI element is a control room design and HSI inventory. The detailed HSI design feeds into the development of the simulator for HFE V&V, training, and validation of procedures.

5.8 Procedure Development

Procedures are essential to plant safety because they guide personnel interactions with plant systems and personnel responses to plant-related events. The objective of procedure development is to apply human engineering principles and guidance to develop procedures that are technically accurate, comprehensive, explicit, easy to use, and validated. To support these objectives, a Procedure Development Plan (PDP) is established. The PDP specifies the inputs and process for procedure development.

The PDP addresses procedures for the operations, maintenance, and inspection/testing of the plant and includes:

- EOPs that are symptom-based
- Abnormal Operating Procedures (AOPs) that are based on events postulated in the safety analysis
- Plant and system operations procedures (startup, normal, and shutdown)
- Maintenance procedures
- Inspection and testing procedures
- Alarm response procedures

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For each procedure type, a procedure writer’s guide is developed. The writer’s guide establishes objective criteria so that the procedures developed with it are consistent in organization, style, and content. The writer’s guide provides instructions for procedure content and format, writing of steps, and specifying lists of terms used. The procedure writer’s guide considers the industry relevant good practices reflected in Procedure Professionals Association (PPA) AP-907-005 (Reference 13).

The procedures developed by this HFE technical element are used for ISV, as described in Section 5.10. Following ISV, the procedures are provided to the plant operator to use as the bases for pre-operational testing, startup testing, and eventually continued operation of the plant.

5.9 Training and Qualification Program Development

A training program for plant personnel is important to ensure nuclear power plants are operated in a safe manner. For the project, a Training Program Development Plan (TPDP) is established to specify a systematic approach to training. The approach is applied to positions included in the minimum staff complement described in Section 5.4.

The TPDP addresses the requirements and guidance provided in NRC Regulatory Guide 1.8 (Reference 14), which endorses American National Standards Institute (ANSI) /American Nuclear Society (ANS)-3.1-2014 (Reference 15), with certain exceptions and clarifications listed in the Regulatory Position of Reference 14.

The TPDP includes the following fundamental stages of a systems approach to training:

1. Analysis
2. Design
3. Development
4. Implementation
5. Evaluation

The analysis stage determines the training needed for the specified job position based on assigned tasks. Tasks that support plant functions are identified as part of detailed and basic TA, which is described in Section 5.6. Tasks are selected for training based on Difficulty, Importance, and Frequency (DIF). Depending on the DIF ranking, a decision is made to determine if initial training and periodic retraining is needed. This evaluation of training tasks is the training equivalent to grading HAs presented in Section 3. The results of the analysis presented in Section 3 inform the DIF importance selection.

Tasks that are selected for training are analyzed to determine the required Skills, Knowledge, and Abilities (SKA). The SKA necessary for each job position, including entry-level education, training, and experience is established to support training design.

During the design stage, learning objectives are developed, and a description of the plan for training, including methods and settings, is established. The completion of the design stage establishes the input that is needed for the development stage.

In the development stage, lesson plans and instructional materials are created, and assessment tests are established. At the end of the development stage, the training package is reviewed, piloted on trainees, and revised if necessary.

In the implementation stage, instructors prepare for and deliver the training. Trainees are tested to determine if they have mastered the objectives. The results of the trainee tests are examined during the evaluation stage. The evaluation stage examines the effectiveness of the training as delivered. This appraisal is done through the review of training results, training feedback, and continual monitoring of work performance.

A training program provides assurance that plant personnel have the SKA needed to perform their roles and responsibilities. Participants used for ISV, as described in Section 5.10, are trained using this program and provide validation of the integrated design.

5.10 Human Factors Verification and Validation

HF V&V (further defined in Section 9) is a V&V of plant HSIs and the working environment where HSIs are used. HF V&V is conducted in two major activities: HF verification (design and task support) and HF validation. HF V&V is conducted by a team of HF engineers independent from the design development process. HF V&V is performed on a configuration-managed, baselined design and includes the following areas:

- Control area and equipment layout
- Panel and console dimensions
- Hardware-based indications, controls, alarms, and panel layout
- Software-based HSI displays, controls, alarms, and display layout

HF design verification verifies that the HSIs, as defined and baselined in the HSI inventory and characterization, are evaluated against the HFE design requirements contained in the HFE DRD. HF Task Support Verification (TSV) verifies that the HSIs, as defined and baselined in the HSI inventory and characterization, include the necessary features (e.g., controls, information displays, and alarms) required to support tasks and that there are no unnecessary features. [[

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HF design verification and TSV use multiple evaluation tools and testbeds, as appropriate to the verification scope, to verify that the overall HSI design (including task sequencing, timing, and procedures) conforms to the design criteria provided by the HSI DRD and TAs, respectively. Verification methods are:

- Analysis using paper-based or software-based drawings to verify static design features (e.g., dimensions, layouts, labelling, access)
- 3D mock-ups (virtual or physical) to verify physical characteristics of the control room layout, panels, and consoles
- Simulation/stimulation using a computer-based workstation platform or a glass-top simulator platform to verify dynamic design features and HSI function

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]]$^{(a)(4)}$ The HF verification activities are performed and any resulting HEDs are resolved prior to the initiation of ISV.

HF ISV is an integrated, dynamic, performance-based test activity where participants are subjected to a set of simulated scenarios that represent a realistic, challenging, and generalizable set of conditions demonstrating that the integrated HSI supports safe operation of the plant.

A multi-phased testing and validation approach allows for the ID and resolution of HF issues earlier in the design process. Once the HSI design, procedures, simulation model, and test platform are sufficiently mature to support the necessary fidelity to obtain meaningful results (findings being due to an actual HF issue and not due to testbed limitations), dynamic scenarios are run on a testbed using a set of participants that represent the defined users of those HSIs and procedures in the HFE COO. Assessment of appropriate testbed fidelity is informed by industry standards, such as IEEE 2411-2021 (Reference 16).

During conceptual and the early portions of basic design, testing is smaller scale and iterative in nature, focusing primarily on HSI usability and compatibility with task performance. This testing is performed by the HSI designers for rapid feedback back into the design process and is not considered a validation because it does not include the same independence requirements for test designers, administrators, and observers; the same level of training, qualifications, and independence for participants; nor the same level of design maturity and configuration control.

Once portions of the design (HSI, simulation, and procedures) reach a sufficient level of maturity, fidelity, and configuration control, partial validations can be conducted on a part-task simulator by sufficiently qualified test personnel and participants who are independent from design of the HSI and procedures in accordance with the HF V&V plan. The participants selected for early validation activities can include personnel with plant operating and maintenance experience or system designers familiar with the set of systems being tested. The crews used during ISV activities include personnel trained to become operators, maintainers, and trainers for the project.

The HF ISV pilot and ISV are performed on a simulator that is a high-fidelity representation of the hardware-based and software-based controls, indications, alarms, and user input devices at the control area. ISV simulator testbeds provide the fidelity required for the validation conducted to be meaningful and valid.

The use of an operational condition sampling process ensures that a broad and representative range of operating conditions is included in the sample population of ISV scenarios. A weighted list of operational conditions ensures a representative sample emphasizes safety significance, risk, and challenges to the operating crew. [[

]]$^{(a)(4)}$ The output of the operational conditions sampling and scenario development process is a group of simulator scenarios that allow for the evaluation of the plant design and user interfaces.

HF ISV evaluates the performance of the integrated HSI design in terms of plant metrics, personnel tasks, crew communications and coordination, situation awareness, workload (cognitive demands, multi-tasking, occupational stress), anthropometric, and physiological (ergonomic) factors. HF ISV scope includes validation of:

- Plant personnel roles, staffing and qualifications, task assignment, and crew coordination
- Procedure adequacy
- Automation functions
- Integrated HSI design, configuration, function, and user support

- Important personnel tasks accomplished within the evaluated time frame and performance criteria
- Acceptable crew situation awareness and workload levels
- Training

A plan is developed detailing HF V&V methodology (Appendix D). The HF V&V plan includes the following content areas:

- HF V&V schedule and dependencies
- HF V&V personnel roles, qualifications, and independence criteria
- HF verification proportionate sampling methodology, procedures, tools, and documentation
- HF ISV operational condition sampling and scenario development; testbed definition and fidelity requirements; participant selection criteria, qualifications, and training; test design; performance measures and acceptance criteria; data collection, analysis, and interpretation; documentation
- HF V&V HED ID, documentation, prioritization, analysis, and resolution

The HF V&V plan is developed to meet the review criteria of NUREG-0711 (Reference 3). In addition, the HF V&V plan includes relevant good practices provided in NUREG/CR-6393 (Reference 17), International Electrotechnical Commission (IEC) 61771:1995 (Reference 18), and IEEE 845-1999 (Reference 12).

5.11 Design Implementation

The design implementation addresses the final as-built implementation of the HFE design requirements into plant design. The following activities are conducted during design implementation, and the detailed methodology is developed in the HF design implementation methodology plan:

- Confirm that the final as-built HSIs, procedures, and training conform to the design resulting from the HFE design process and V&V activities.
- Evaluate any deviations from the design during implementation and identify their effect on the HFE aspects of the design.
- Perform final procedure validation on the physical plant hardware.
- Verify aspects of the design that may not have been evaluated previously in the V&V process. This includes any hardware/software, and new or modified displays that were absent from the simulator-based integrated V&V process; and any physical or environmental (e.g., noise, lighting) differences between those present at the V&V process and the as-built control areas.
- Verify resolution of remaining HEDs and open items from HFEITS.
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Design implementation activities are performed by the HFE team. HFE deficiencies identified during commissioning are addressed prior to declaring the system available for service.

5.12 Human Performance Monitoring

Human performance monitoring is performed by the operating entity at the plant site throughout the operational phase of the plant. Human performance monitoring is used to track metrics of human performance to ensure that the acceptable level of performance achieved by the integrated HFE design during HFE V&V is maintained. A human performance monitoring plan details the process for monitoring HAs based on risk level, detecting performance degradations, and providing HF solutions.

6 PROCESS AND PROCEDURES

6.1 General

The HFE program is executed in accordance with the project design process and project quality plan. This work is performed in an integrated manner through a detailed schedule that identifies the activities and deliverables necessary to complete the design. The schedule includes activities and deliverables for associated disciplines (e.g., I&C, HFE, mechanical, electrical) and orders them with logic connections to ensure they are completed in the required sequence.

6.2 Timelines

HF work occurs within the context of the project integrated schedule. Workflows are timed including sequencing inputs from, and outputs to, other disciplines at the correct times and project phases to meet requirements and commitments.

6.3 Requirements Management

HFE requirements management is performed in accordance with the project requirements management process.

HFE requirements are categorized and dispositioned as follows:

- Process Requirements – Requirements for the way the HFE program is conducted and for the interfaces between HFE and other disciplines. [[

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- Product Requirements – Requirements for the design of, or provision for, environmental attributes, SSCs, and HSIs. [[

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Where HF inputs are not in agreement with one another, precedence is given as follows:

1. [[

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Conflicts between HFE design requirements and performance-based requirements that are identified during requirements consolidation for design implementation, HSI design tests and evaluations, and HFE design verification are resolved using the HFE issue and HED resolution process described in Section 6.4.

6.4 Identification and Disposition of Human Factors Engineering Issues

HFE issues and HEDs are tracked using HFEITS, which facilitates resolution of problems, issues, and HEDs by providing the means to record and track issues throughout the design process life cycle, development, and evaluation.

HFEITS is used to support the following functions:

- Evaluation of HEDs to determine their significance and whether the HED warrants correction when evaluated in the context of the integrated plant design
- ID of appropriate solutions to address issues/HEDs including changes to HSI design, procedures, staffing, qualifications, or training
- Verification that the solutions implemented to address the issue/HED resolves the problem without generating additional issues/HEDs
- Documentation or traceability of the issue/HED resolution process

Details regarding specific considerations and processes for HFE issues and HED management are contained in Section 8.

7 Human Factors Engineering Application Levels by Technical Element

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Table 7-1: Human Factors Engineering Application Levels

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Table 7-1: Human Factors Engineering Application Levels

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8 HUMAN FACTORS ENGINEERING ISSUE AND HUMAN ENGINEERING DISCREPANCY IDENTIFICATION AND DISPOSITION

The following sections contain HF discipline-specific definitions, criteria, and processes.

8.1 How to Identify Human Factors Engineering Issues and Human Engineering Discrepancy

An HFE Issue is placed into HFEITS when:

- The HFE issue is discovered out-of-process and therefore cannot be currently resolved through the normal HFE process.
- The HFE issue requires tracking until it can be resolved via the normal HFE process.

An HED is placed into HFEITS when:

- A deviation from an HF DRD requirement is discovered during HF design verification.
- There are information and control requirements identified by TA that have not been met by an HSI during TSV.
- There are HSIs identified during TSV that are not needed to support personnel tasks.
- Acceptance criteria are not met during ISV.

8.2 Criteria for Prioritizing Human Factors Engineering Issues and Human Engineering Discrepancies

Table 8-1 provides guidance for prioritizing HFE issues and HEDs. The HF priority is included in the issue summary. Information is initially populated by the originator and updated by the issue owner.

Table 8-1: Human Factors Engineering Issue and Human Engineering Discrepancies Prioritization Criteria Summary

HF Priority	Definition
1 - Highest	Safety consequences (either direct or indirect) – A condition (equipment, HSI, procedure, training, or staffing deviation, deficiency, or nonconformance) or adverse trend that has the potential to affect an [[ ]]$^{(a)(4)}$.
2 - High	Plant or personnel performance effect – A condition (equipment, HSI, procedure, training, or staffing deviation, deficiency, or nonconformance) or adverse trend that has the potential to affect an [[ ]]$^{(a)(4)}$.
3 - Low	Enhancement (neither safety consequential nor affecting performance) – A condition (equipment, HSI, procedure, training, or staffing deviation, deficiency, or nonconformance) or adverse trend that deviates from the HFE DRD or HFE principles that has neither safety nor risk consequences.

8.3 Human Engineering Discrepancy Cumulative Effects Analysis

The cumulative effects of HEDs on the HSI resources, control room, training, plant procedures, or staffing and work organization may have greater effect on human performance and the likelihood of human errors than the individual HEDs. Thus, cumulative effects result from HEDs that are individually minor but collectively significant.

Cumulative effects analysis is conducted by the issue owner, using qualitative techniques and subject matter expertise and judgment. After becoming familiar with the HEDs through the process of reviewing, prioritizing, and categorizing the HEDs, the issue owner determines if there are individual HEDs that merit grouping together to assess the cumulative effects of the HEDs and to facilitate resolution.

Related HEDs are grouped for analysis of their interactions and combined effects:

- HEDs that affect the same HSI resource
- HEDs that affect the same function or task
- HEDs from different originating activities but relate to same issue
- HEDs related to inconsistency between HSIs
- HEDs with same underlying cause
- HEDs for separate HSI resources that share the same problem

An HED that meets any of these criteria is placed in the respective group for analysis of the interactions between the HEDs in that group and their combined effects on human performance. Additionally, during analysis it is determined if priority escalation is needed for any of the HEDs due to concerns raised by cumulative effects.

When examining related HEDs in the context of other existing HEDs, the issue owner notes any potential conflicts that may occur when determining resolutions to the individual HEDs. The results of this evaluation are used to help determine the most appropriate overall resolutions.

Based on the information resulting from the analysis, the issue owner draws conclusions about the cumulative effects to HAs [[ ]](a)(4).

Once the issue owner has determined what potential cumulative effects exist, the issue owner uses the results of the analysis to determine the severity or magnitude of the cumulative effect and how this may affect the priority of the affected HEDs. If priority is changed, rationale is also included. [[ ]](a)(4)

The results of cumulative effects analysis are attached to the relevant issues, including reference to the tracking number of the HEDs. The results provide suggestions for addressing or mitigating the identified effects.

8.4 Confirmation of Human Engineering Discrepancy Resolution

Once the assignee has completed design revision or disposition actions, the issue owner determines, based on the HED types described in Sections 8.4.1 to 8.4.4, the means to check the adequacy of the revised design, procedures, training program, and staffing plan.

The issue owner then assigns, notifies, and briefs the individuals who conduct review, verification, and validation of the HED resolution.

8.4.1 Human Engineering Discrepancy Justification Review

Justifications are reviewed and verified [[ ]]$^{(a)(4)}$. If the justification is not deemed acceptable, the issue owner revises the justification based on feedback or escalates the issue as needed. If the justification is acceptable, acceptance is included in issue resolution documentation and the HED proceeds to closure.

8.4.2 Human Engineering Discrepancies Requiring Static Human Factors Verification

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Verification may only occur on completed, approved, formally issued, configuration-controlled product releases. Verification results and methodology are included in the issue resolution documentation.

[[ ]]$^{(a)(4)}$ If new HEDs are found as a byproduct of the verification process, these HEDs are fed back into the HFEITS as new HEDs.

8.4.3 Human Engineering Discrepancies Requiring Dynamic Human Factors Retesting

For HEDs that originated from HF ISV activity, the issue owner determines the appropriate validation strategy, using a graded approach, based on the complexity and effect of the changes. For this category of HED, the HF verifier acts as lead on retesting activities, implementing the verification plan laid forth by the issue owner, overseeing the testing, generating the test report, and documenting conclusions and acceptability.

Priority 1 and 2 HEDs require retesting with participants not previously exposed to the test scenario(s). This provides assurance that the HSI resources, control room design, training, procedure, and staffing changes now satisfy the applicable test criteria.

For Priority 3 HEDs, where HED resolution was relatively straightforward and required minimal changes, and where it is unlikely that the changes affect the performance of the integrated system as whole, alternate re-assessment methods may be used. In these cases, the assessment of the effectiveness of the resolution may be done using one or more of the following methods:

- Walk-through assessment
- Performance-based small-scale retesting utilizing personnel with an operations background as subjects

[[ ]]$^{(a)(4)}$. If any of the re-assessment activities result in the ID of the same HEDs, these HEDs are updated and returned to the issue owner for resolution. If re-assessment activities result in the ID of new HEDs, these HEDs are fed back into the HFEITS as new HEDs.

8.4.4 Deferred/As-Built Human Engineering Discrepancies

For HEDs that cannot be resolved or verified until a specific design lifecycle milestone is reached, the issue owner makes this designation in HFEITS and ensures the HEDs are tracked until resolution can occur.

9 DEFINITIONS

Term	Definition
Accident	Event that has the potential for release of significant amounts of radioactive material.
Action	An observable movement during task performance.
Alarm	In the broad sense, a plant parameter, component, system, or function that is currently in a state requiring the attention of plant personnel. For example, a monitored parameter exceeds a specified limit (setpoint), the deviation is evaluated by the processing portion of the alarm system, and a message is conveyed.
Allocation of Function	Assignment of responsibility for performing operations required for accomplishing functions to humans, machines, or some combination of both.
Component	The meaning of the word component depends on its context. In context of the entire plant, it is an individual piece of equipment such as a pump, valve, or vessel and is typically part of a plant system. In an HSI context, a component is one part of a larger unit, such as a meter in a control board. In a maintenance context, a component is a subdivision of a unit of equipment that can be treated as an object by the maintainer, but which can be further broken down into parts. A mounting board together with its mounted parts is an example of a component.
Crew	The group of people at the plant who manage and perform activities necessary to operate the plant and maintain its safety as performed during simulations.
[[ ]]$^{(a)(4)}$	[[ ]]$^{(a)(4)}$
Data Connection Table (DCT)	A table that lists the Input/Output (I/O) points associated with a HSI element on a display or panel.
Detailed HSI Features	Aspects of individual HSIs that are not addressed by general HFE guidelines. These features are specific to the unique application of each HSI, such the exact wording on individual component tag labels. These HSI features are more variable than standardized design features and are verified in accordance with the methodology described in the sampling of operational conditions.

Term	Definition
Ergonomics	Static and dynamic evaluations of measurements, angles, and usability in the working space in relation to a user population to confirm the reach and accessibility of control devices, visibility of indication, and seating comfort.
Event	Any planned (for example, power change) or unplanned (for example, process system component failure) occurrence that affects operation of process systems in such a way that achievement of required safety and productivity levels is jeopardized.
Faceplate	An HSI panel or window used to control a component and display relevant information about the component including the current state, allowable transitions, and historical alarms and trends.
Feedback	System or component response (for example, visual, auditory, and tactile) indicating the extent to which the user's desired effect was achieved. Feedback can be either intrinsic or extrinsic. Intrinsic feedback is what the individual senses directly from the operation of the control devices (for example, clicks, resistance, and control displacement). Extrinsic feedback is what the individual senses from an external source that indicates the consequences of the control action (for example, indicator lights, display changes, and aural tones).
Full-Scope Simulator	A high-fidelity simulation environment that includes physical and environmental aspects, and HSIs of the operating environment. Typically, this refers to the control room simulator and meets the requirements of IEEE 2411-2021 (Reference 16).
Global HSI Features	Features related to the configurational and environmental aspects of the HSI, such as work area layout, general workstation configuration, lighting, noise, heating, and ventilation. These aspects of the review, such as lighting, tend to be evaluated only once.
Human Engineering Discrepancy	A departure from some benchmark of system design suitability for the roles and capabilities of the human operator. This may include a deviation from a standard or convention of human engineering practice, an operator preference or need, or an instrument/equipment characteristic that is implicitly or explicitly required for an operator's task but is not provided to the operator.
Human Factors	A discipline concerned with the systematic study and application of what is known about human behavior to system development decisions.
Human Factors Engineering	The application of knowledge about human capabilities and limitations to plant, system, and equipment design. HFE ensures that the plant, system, or equipment design, tasks, and work environment are compatible with the sensory, perceptual, cognitive, and physical attributes of the personnel who operate, maintain, and support it.
Human Factors Engineering Issue	A problem or finding that is known to the industry or is identified throughout the life cycle of the HFE aspects of design, development, and evaluation. Issues are items that need to be addressed later and are tracked to ensure they are not overlooked.

Term	Definition
Human Factors Engineering Issue Tracking System	An electronic database used to document HFE issues not resolved through the normal HFE process and HEDs from the HFE V&V. Additionally, the database is used to document the problem resolutions.
Human Factors Engineering Testing and Evaluation	Tests and evaluations of concepts and detailed design features conducted during the process of developing HSIs to support design decisions. HFE T&E is part of the iterative HSI development and rapid prototyping process, in which an HSI design concept or prototype is evaluated by HFE subject matter experts and tested by a sample of participants who are representative of the HSI end users to evaluate the design's efficiency, effectiveness, and degree of perceived usability for the intended population.
Human Factors (Engineering) Verification and Validation	HF V&V evaluates completed design features including alarms, controls, indications, and their associated hardware. During HF V&V, design features are compared with regulatory requirements and guidance, HFE requirements, and the requirements generated during analysis of tasks. HF V&V consists of design verification, TSV, and ISV. Verification is the process of determining and documenting that an implemented design (e.g., a product, process, procedure, method) meets its specifications. Verification answers the question: Was the design implemented appropriately? Validation is performance-based testing of a component, sub-system, or system prior to its placement in-service, to assess reasonable confidence of compliance with functional and operational requirements. Validation answers the question: Was the appropriate design implemented?
Human-System Interface Element	A software or hardware-based piece of an HSI display or panel. Examples of HSI elements include, but are not limited to components (symbols, controls, and status indications), parameters (numerical readouts, bar charts, trend graphs), alarms (symbols, sounds, and messages), and user interfaces (faceplates, menus, toolbars, scrollbars).
Human-System Interface Element Library	The entire inventory of HSI elements implemented in compliance with the HFE DRD and the HSI style guide, and electronically available to construct HSI display or panel drawings.
Human-System Interfaces	The means through which personnel interact with the plant including the alarms, displays, controls, and job performance aids. This includes interfaces for operations, maintenance, test, and inspection interfaces.
Input	The term input is context contingent and may take these forms: • Information entered into a system for processing. • Process of entering information. • Pertaining to the devices that enter information.
Link Analysis	A process used to analyze layout of equipment and consoles based on task demands by determining links (physical movements and changes in attention or gaze) in a system between interface components (controls, indications, and alarms) and operations.

Term	Definition
Local Field Interface	An operator interface related to process control that is not located in the control room. This includes multifunction panels, as well as single-function field interfaces, such as controls (for example, valves, switches, and breakers) and displays (for example, meters) that are operated or consulted during normal, abnormal, or emergency operations.
Monitoring	Purposefully observing displays to assess plant operations. If available information suggests abnormality, additional information is sought, and a diagnosis of the difficulty is performed.
Panel	Any surface upon which measures of equipment behavior are displayed or controls that directly affect equipment operations are contained. This includes display pages presented on VDUs, as well as conventional console panels containing hard controls.
Parameter	Any physical property whose value reflects a plant condition.
Plant Safety	Also called safe operation of the plant. A general term used to denote the technical safety objective of preventing accidents in nuclear plants. This includes verifying that, for accidents considered in the design of the plant, even those of very low probability, any radiological consequences are minor. This also includes providing reasonable assurance that the likelihood of severe accidents with serious radiological consequences is extremely small.
Probabilistic Risk Assessment	A qualitative and quantitative assessment of the risk associated with plant operation and maintenance that is measured in terms of frequency of occurrence of risk metrics, such as core damage or a radioactive material release and its effects on the health of the public.
Procedures	Written instructions providing guidance to plant personnel for operating and maintaining the plant and for handling disturbances and emergency conditions.
Pugh Matrix	A criteria-based decision matrix that uses weighted scoring to help determine which among several potential design solutions or alternatives should be selected.
Standardized Human-System-Interface Features	A standard set of features or HSI elements that have been designed in accordance with the HSI style guide and HFE design requirements. For example, display labeling font size and color, contained within an HSI element library, developed and standardized in accordance with the HSI style guide, can be verified within the standard library, and then spot-checked for a subset of applications, in accordance with the sampling of operational conditions, rather than having every occurrence verified individually.
Symbol	A particular type of graphical display element used in an HSI. The types of elements include icons, bar graphs, message boxes, real-time numerical data indicators, and function buttons for process control.
Timeline Analysis	An analytical technique used to assess expected task duration for comparison with allowable timescales to determine if success criteria can be met.

Term	Definition
Trend	Information in the form of a graph or plot displaying performance of a variable or variables over time.
Usability Testing	Usability testing uses a sample of participants to determine suitability of a design for the user population, and acceptability of a design to support user task performance through interaction with an HSI T&E prototype or testbed.
User Interface	An interface that enables information to be passed between a human user and hardware or software components of a computer system.

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Appendix A: Human Factors Engineering Allocation of Function and Task Grading Methodology

A.1 INTRODUCTION

A.1.1 Purpose

This appendix details the process of AOF, which is part of the HFE program. The need and requirements for AOF are established in Section 5.3.

The AOF process establishes a plant control scheme that enhances plant safety and reliability by taking advantage of human and system strengths and avoiding human and system limitations. The AOF process also addresses human vigilance, situation awareness, and acceptable workload.

This appendix also describes the task grading process, used to determine the HFE application level, which guides the risk-based proportionate approach to HFE activities within the HFE program. The task grading process is carried out after the initial AOF is developed, using the decomposed functions as input to the task-based risk grading process.

A.1.2 Scope

The process of AOF applies to functions and tasks that support system functional requirements and require human or machine actions to be performed (non-passive) to achieve plant functional goals.

A.2 ALLOCATION OF FUNCTION METHODOLOGY

The AOF methodology applies to functions and tasks that support system functional requirements and require human or machine support to execute (non-passive). The first step in the AOF process is to perform initial allocations, as described in Section A.2.1. Once initial allocations are complete, they are evaluated to determine adequacy within the larger integrated work environment, as described in Section A.2.2. Background information provided in Section A.6 describes the references used to develop the AOF process.

A.2.1 Allocation of Function Definition

The AOF process establishes an initial (hypothesized) task allocation based on expert judgment from a panel that includes [[ ]]$^{(a)(4)}$. The panel makes use of OE as well as information from additional SFR subject-matter experts to determine how similar applications were allocated and to evaluate how those allocations performed.

[[ ]]$^{(a)(4)}$ In addition, with the conversion of functions to tasks, multiple tasks may be necessary to support the function. The support tasks require a task allocation that uses the same criteria applied to AOF. The PRA also provides input to the AOF, specifying when HAs are modeled to back up automatic (machine) actions.

The process for conducting the hypothetical AOF is illustrated in Figure A.2-1. The process Steps A through J are listed and described in Table A.2-1. The AOF data is recorded using a spreadsheet. An example spreadsheet is shown in Section A.5.

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Figure A.2-1: Initial Allocation of Function Definition Process

Table A.2-1: Initial Allocation of Function Definition Steps

Step ID	Step Statement	Description
A	Function or Task	Functions and tasks based on the system requirements. For each function or task, record, in the results, the system name, main parts list identifier, function or task name, and source.
B	Machine Sequence Mandatory?	The criteria or considerations for a mandatory machine sequence are: 1. Machine sequence is specified or assumed by: a) Regulatory, customer, or plant requirement b) Safety analysis c) PRA 2. Working environment, such as atmosphere, temperature, or radiation, does not allow performance by human and task cannot be done remotely. 3. Task requires large, precise, or extended application of force (from Reference 7). 4. Task requires precise measurements or calibrations. 5. Task requires a performance or a response that exceeds human capabilities. [[ ]]$^{(a)(4)}$

Table A.2-1: Initial Allocation of Function Definition Steps

Step ID	Step Statement	Description
C	HA Sequence Mandatory?	The criteria or considerations that result in mandatory HAs are: 1. HA specified by regulatory or customer requirements 2. HA claimed in or required by the safety analysis and PRA 3. Task requires capabilities that are unique to humans (from Reference 7): a) Operations cannot be reduced to preset procedures b) Form and content of inputs and outputs cannot be specified or predicted c) Relationship between inputs and outputs may require restructuring during task performance d) Evaluation is made of the performance of others or individual (self) e) Performance of a system or function requires that meaning and relative values be assigned to events For any "Yes" answers, record in the criteria column the number(s) for the corresponding criteria or considerations that support the conclusion that HA is mandatory. For Criterion C.1, add a document reference to identify the basis for the mandatory human sequence. Also, consider the required regulatory or customer need against other criteria that might dictate a machine sequence instead.
D	Feasible for Human?	[[ ]](a)(4) assess if the human satisfies the high-level performance requirements: 1. Ability to detect 2. Response time limits 3. Reliability of response 4. Acceptable cognitive workload 5. Acceptable physical workload For any "No" answers, record in the criteria column the number(s) for the corresponding criteria or considerations that prevent human task performance.

Table A.2-1: Initial Allocation of Function Definition Steps

Step ID	Step Statement	Description
E	Feasible for Machine?	Determine if the task is feasible for the machine within the: 1. [[ ]]$^{(a)(4)}$ For any “No” answers, record in the criteria column the number(s) for the corresponding criteria or considerations that prevent the feasibility of the machine action.
F	[[ ]]$^{(a)(4)}$	Determine if [[ ]]$^{(a)(4)}$ by the following: 1. Machine sequence specified or assumed by: a) Regulatory b) Customer or plant requirement c) Safety analysis d) PRA 2. Harsh working environment is expected, such as toxic atmosphere, high temperature, or unacceptable radiation level. 3. Task requires performance or response that exceeds human capabilities. For any “Yes” answers, record in the criteria column the number(s) for the corresponding criteria that [[ ]]$^{(a)(4)}$. For allocations based on Criterion F.1, document the source and justification with consideration to task requirements. Also, consider the required regulatory or customer need against other criteria that might dictate human participation in an automated sequence.
G	Allocation Informed by OE?	Where a predecessor system exists, determine if it is preferred to allocate to the human, machine, or shared, considering this function against the OE. Review any problems with the existing application for allocation issues. For any “Yes” answers, record in the results and describe or reference the OER in the notes column.

Table A.2-1: Initial Allocation of Function Definition Steps

Step ID	Step Statement	Description
H	[[ ]]$^{(a)(4)}$	Base the [[ ]]$^{(a)(4)}$ on the following: 1. Feasibility for machine or human (criteria for Step D and Step E) 2. [[ ]]$^{(a)(4)}$ 4. Information from OER (Step G) Humans are prohibited from the following (from Reference 7): 1. Tasks that require unvarying repetition 2. Tasks that cannot be interrupted 3. Tasks that require sustained attention for long periods of time (e.g., exceeding 20 minutes) 4. Tasks that require detecting rarely occurring conditions For selections that are based on humans being prohibited due to the criteria, record in the criteria column the number(s) for the corresponding criteria or considerations that apply to the conclusion.
I	Backup Required?	Backup tasks are required based on: 1. Regulatory or customer requirement 2. Assumption in the PRA 3. Safety analysis requirement or assumption For any “Yes” answers, record in the criteria column the number(s) for the corresponding criteria or considerations that support the conclusion that backup is required.

Table A.2-1: Initial Allocation of Function Definition Steps

Step ID	Step Statement	Description
J	Backup Feasible for Human?	Provide high-level assessment based on available conceptual information if the human can satisfy the performance requirements: 1. Ability to detect 2. Response time limits 3. Reliability of response [[ ]]$^{(a)(4)}$ 4. Cognitive workload is acceptable 5. Physical workload is acceptable For any “No” answers, record in the criteria column the number(s) for the corresponding criteria or considerations that prevent the action being feasible for the human.

The process results in allocations to the machine, the human, or a combination of both, which results in a shared control arrangement. Allocations are evaluated to determine if human or machine backup is needed.

At the end of the allocation definition process, the allocation is defined by a classification that is descriptive of the overall allocation.

A.2.2 Allocation of Function Evaluation

The second stage of the AOF process is the AOF evaluation. While the AOF evaluation methodology is described in this appendix, it is performed later in the design, evaluation, and testing process after TA. In addition, the ID of task requirements to accomplish the functions and tasks that were allocated in whole, or in part, to humans is performed during TA.

The AOF evaluation is a structured examination of function and task groupings that is used to assess allocations in a collective manner within an integrated work environment (instead of an item-by-item basis where issues are less likely to be revealed). The integration of the allocated functions and tasks is formed through scenario development and is then evaluated to determine acceptability based on task performance, workload (physical and cognitive), and situation awareness as a part of integrated TA.

The AOF evaluation process is shown in Figure A.2-2. The evaluation process is performed as part of staffing analysis, HSI test and evaluation, and HFE V&V. If any of these evaluations identify issues with performance, workload, or situation awareness, the contributing functions and tasks are re-examined starting with the AOF process in Section A.2.1 until satisfactory results are found because the HFE process is iterative.

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Figure A.2-2: Allocation of Function Evaluation Process

A.3 TASK GRADING

In accordance with Section 3, a graded (or proportionate) approach to HFE is applied to the project. The functions and tasks allocated to humans resulting from the initial stage of the AOF definition process are graded based on three risk categories:

A. Nuclear Safety

B. Personnel Safety

C. Asset Protection

A.3.1 Risk Level Determination

Each task is assessed for risk level using Table A.3-1. [[

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Table A.3-1: Risk Level Assessment Matrix

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A.3.2 Human Factors Engineering Application-Level Assessment

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A.4 ALLOCATION OF FUNCTION AND TASK GRADING RESULTS

The AOF and task grading data are recorded in a workbook, which documents AOF, task grading, and TAs as an internal design basis record. [[

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The AOF evaluation process refines the initial allocation, including implementing design and safety analysis modifications where necessary to support changes to the allocation outcome. The optimal AOF is evaluated during ISV testing to confirm that performance, workload, and situation awareness are suitable. The results of the AOF development and refinement activities, as well as specification of the final AOF, are provided in a summary report.

A.5 ALLOCATION OF FUNCTION AND TASK GRADING DATA SHEET EXAMPLE

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Figure A.5-1: Allocation of Function Workbook Example

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Figure A.5-2: Task Grading Workbook Example

A.6 ALLOCATION OF FUNCTION BACKGROUND

Although there were earlier works on AOF, there are two significant documents sponsored by the NRC on the subject that were published following the Three Mile Island accident. The first document was NUREG/CR-2623 (Reference 7). The second was NUREG/CR-3331 (Reference 19).

Approximately ten years later, IAEA-TECDOC-668 (Reference 6) was issued, offering an international perspective on AOF and the earlier NRC works (Reference 7 and Reference 19). IAEA-TECDOC-668 recognized NUREG/CR-3331 (Reference 19) as the "most comprehensive approach to the problem of allocating functions in nuclear power plants," and recognized the preceding NUREG/CR-2623 (Reference 7) as a comprehensive review of AOF. However, IAEA-TECDOC-668 also states that while the NUREG/CR-3331 is comprehensive, "it is questionable whether the methodology proposed is realistic in a true design situation" and that "the methodology consists of many stages of analysis which, if performed for each and every function of a new plant design, would represent a significant engineering resource." Therefore, in lieu of the NUREG/CR-3331 process, IAEA-TECDOC-668 presents an AOF process that it describes as "a pragmatic, and more cost-effective method for assigning functions in the context of a large project."

In 2013, Idaho National Laboratory (INL) developed INL/EXT-13-30117 (Reference 8), which discusses NUREG/CR-3331 (Reference 19) as well as other contemporary works on AOF that are used to establish the foundation for the AOF framework described in this appendix.

The INL/EXT-13-30117 framework uses the following high-level steps from NUREG/CR-3331 as part of its technical basis:

- Prepare for design by organizing a multi-disciplinary team, identifying requirements and system constraints, and creating a records database
- Define functions as either necessary or accessory, and identify each function's inputs, outputs, and relationships to other functions (i.e., dependencies)
- Hypothesize design solutions as a multi-disciplinary design team by proposing an engineering hypothesis, an allocation hypothesis, and an HF solution
- Test and then evaluate the preliminary allocation solution
- Iterate the design cycle to correct errors, optimize the design, and complete the design to an acceptable level of detail

INL/EXT-13-30117 creates a streamlined and straightforward hypothetical AOF process that explicitly addresses functions shared by human and machine. As such, this document is used as one of the primary inputs to the development of the AOF process.

The AOF process is designed to efficiently determine the initial hypothetical allocation using expert judgment without prolonged examination. AOF follows the high-level steps from NUREG/CR-3331 (Reference 19) with input and modernization based on the practical considerations of IAEA-TECDOC-668 (Reference 6) and INL/EXT-13-30117 (Reference 8) with the following additional modifications:

- The AOF process contains the addition of an option to allocate a function or task at a top level based on OE when the same or similar allocation has been employed and there is generalizable performance history.

- [[

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- The AOF process includes input based on NUREG/CR-2623 (Reference 7) for allocation criteria that limit or preclude human participation, as well as criteria that define unique desirable human capabilities.

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Appendix B: Human Factors Engineering Task Analysis and Human-System Interface Design Methodology

B.1 INTRODUCTION

B.1.1 Purpose

This appendix details the TA and HSI development process. The need and requirements for TA and HSI design are established in Section 5.6 and Section 5.7, respectively.

This appendix provides the current methodology for the development of the TA and HSI design processes. Incorporating a formalized HF program into the design processes is necessary to design to the strengths and abilities of the humans who operate and maintain the plant. This document describes the methodology through which TA is completed and how the TA provides input to development of HSIs, procedures, training programs, and HFE V&V.

The TA process analyzes the tasks that are allocated to a human or shared with the machine during the AOF process for human performance needs. This results in procedure outlines and ID of task support requirements.

The HSI process ensures that the task requirements are implemented into the design in accordance with the HFE DRD.

HFE T&E is used to confirm that tasks are properly analyzed, supported, and implemented by the HSI design. The TA process is repeated through the iterative design process and if needed for design modifications.

B.1.2 Scope

The processes of TA, HSI design, and HFE T&E apply to human or machine with human support (non-passive) tasks done within NI plant systems to gain a complete understanding of scope and breadth of human interactions.

B.2 TASK ANALYSIS METHODOLOGY

The TA and HSI development process requirements are described in Section 5.6 and Section 5.7, respectively. The start of the TA process begins with the output of the AOF. Inputs from regulatory sources, system design inputs, safety analysis, and PRA flow through the AOF activities forming the basis for TA.

B.2.1 Task Analysis Inputs

Various inputs are used for the development of the TA and flow into HSI development. These are divided into the categories described in Sections B.2.1.1 and B.2.1.2.

B.2.1.1 System Design Inputs

System design inputs include the system design details down to the component level. This includes the narrative for how the system functions and reacts to various inputs and through its modes of operation.

System design inputs to TA include, but are not limited to, the following information sources:

- [[

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- Applicable TA OE
- Applicable tasks that were allocated during the AOF process

B.2.1.2 Plant Information

Plant-level information is also used during both system-level and integrated (plant-level) TA. This includes the narrative for how the plant functions and reacts to various inputs and through its modes of operation, as well as [[

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Plant information inputs to TA include, but are not limited to, the following information sources:

- [[

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B.2.2 Task Analysis Process

The task inputs provided by the AOF and task grading process form the starting point for TA. These tasks are divided into levels of effort as defined through the task grading portion of the AOF process.

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The resulting TA information is documented within a system or integrated (plant-level) TA and HSI design workbook. This workbook contains the information needed by the following processes:

- Staffing and qualifications
- HSI development
- Training development
- Procedure development

B.2.2.1 Review of System Relevant Operating Experience

Prior to conducting TA, the HFE COO is reviewed to identify applicable OE-based TA considerations. Any OE-based considerations found are identified in the applicable OE portion (Figure B.2-1) of the TA and HSI design workbook.

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]]$^{(a)(4)}$

Figure B.2-1: Applicable Operating Experience

B.2.2.2 Review of Task List

The TA identifies and analyzes the task steps that comprise the identified tasks based on Figure B.2-2 in the TA and HSI design workbook. This task list is derived from the AOF and task grading process.

The task list also includes documentation of the [[

]]$^{(a)(4)}$.

The resulting list of tasks are then analyzed through the series of TA steps outlined in Sections B.2.2.3, B.2.2.4, and B.2.2.5.

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Figure B.2-2: Task Analysis Input Task List

B.2.2.3 Creation of Human-System Interface Identification List

Prior to performing the TA, system design inputs and plant information documents are reviewed, and a pre-job briefing is held with HFE and the system designer to ensure an understanding of the TA and HSI design process and the system design.

Applicable inputs and references are documented within the design inputs and references (Figure B.2-3) portion of the TA and HSI design workbook.

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Figure B.2-3: Design Inputs and References

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Figure B.2-4: Human-System Interface Identification List

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B.2.2.4 Task Step Sequence Narrative

For each task in the TA input task list (Figure B.2-2), Figure B.5-1 is populated within the TA and HSI design workbook following the process described in Table B.2-1.

Table B.2-1: Task Step Sequence Narrative Definition Process

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Table B.2-1: Task Step Sequence Narrative Definition Process

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Table B.2-1: Task Step Sequence Narrative Definition Process

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Table B.2-1: Task Step Sequence Narrative Definition Process

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Table B.2-1: Task Step Sequence Narrative Definition Process

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Table B.2-1: Task Step Sequence Narrative Definition Process

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B.2.2.5 Task-Level Support, Job Design, Workload, and Workplace Definition

Once the task step sequence narrative is completed, the supporting information necessary for the task is entered in the TA and HSI design workbook concerning:

- Supporting SSCs [[ ]]$^{(a)(4)}$
- Task support (job aids and tools)
- Job design and preliminary workload analysis coupled with the workplace design and layout organization (for each person involved in the task and each location that the task is to be performed)
- HSI indications – key parameters [[ ]]$^{(a)(4)}$

B.2.2.5.1 Supporting Structures, Systems, and Components

The task-level support needed from other SSCs is derived during the development of the task step narrative [[

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Table B.2-2: Supporting Structures, Systems, and Components Definition

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		]]$^{(a)(4)}$

B.2.2.5.2 Task Support

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Table B.2-3: Task Support Definition

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B.2.2.5.3 Job Design, Preliminary Workload Analysis, and Workplace Design and Layout Organization

The expected workplace and environment provide contextual information for the working conditions under which a task is performed and illustrates some of the unique challenges or qualifications associated with task performance. [[

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Table B.2-4: Job Design, Preliminary Workload Analysis, and Workplace Design and Layout Organization Definition

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Table B.2-4: Job Design, Preliminary Workload Analysis, and Workplace Design and Layout Organization Definition

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Table B.2-4: Job Design, Preliminary Workload Analysis, and Workplace Design and Layout Organization Definition

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Table B.2-4: Job Design, Preliminary Workload Analysis, and Workplace Design and Layout Organization Definition

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Table B.2-4: Job Design, Preliminary Workload Analysis, and Workplace Design and Layout Organization Definition

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Table B.2-4: Job Design, Preliminary Workload Analysis, and Workplace Design and Layout Organization Definition

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B.2.2.5.4 Human-System Interface Indications – Key Parameters

Key parameters are the subset of parameters from the task step sequence narrative (Section B.2.2.4) that are the most important for understanding overall system status and for supporting system monitoring tasks. Key parameters are derived from the main function(s) of the system and are identified through the AOF process and the parameters that are indicative of the system achieving the function(s).

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Table B.2-5: Human-System Interface Key Parameters Definition

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B.2.2.5.5 Operating Experience Associated with Task

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B.2.3 Integrated Task Analyses

An integrated (plant-level) TA is conducted for those operations that require interaction with multiple systems, across multiple plant states, and with a coordinated response that may involve multiple plant personnel. The integrated TA takes the system-level TAs and the [[ ]]$^{(a)(4)}$ and performs higher-level whole sequence analyses such as integrated workload analysis and timeline analysis. [[

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- Group view displays shared by control room personnel
- Supervisory displays
- Potential aggregate display and control HSIs
- Control room and plant HSI location and workspace design considerations
- Staffing input as a result of aggregate workload and work location considerations
- Development of operating procedures that address the various scenarios and plant states analyzed
- Scenario selection for ISV

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B.3 HUMAN-SYSTEM INTERFACE DESIGN METHODOLOGY

The HSI design is standardized with HSI features that enhance the ability of user to carry out monitoring, planning, and response tasks. The primary goal for HSI design is to facilitate safe, efficient, and reliable user performance of tasks during normal, abnormal, emergency, and accident plant conditions. User task types are considered, including operations, maintenance, test, surveillance, and inspection activities using a proportionate level of rigor. To achieve this goal, information displays, controls, and other interface devices are designed and implemented in a manner consistent with good HFE practices.

The following guiding design principles and considerations are incorporated into the HSI design process:

1. HSI design promotes efficient and reliable operation through application of automated operation capabilities.
2. HSI design uses proven technology.
3. The workstation and HSI layouts align with defense line principles driven by other disciplines such as I&C.
4. HSI design is highly reliable and provides functional redundancy such that displays and controls are available in the necessary control locations to conduct an orderly reactor shutdown and to cooldown the reactor to safe shutdown conditions, even during design basis equipment failures.
5. Accepted HFE principles and methods are used for ensuring HFE is integrated into the design.
6. HFE design requirements are based on HF standards and applicable regulatory requirements.
7. Safety parameter displays indications are integrated into the HSI design.

The HSI is designed to support personnel in their primary role of monitoring, controlling, and maintaining the plant while minimizing personnel demands associated with use of the HSI (e.g., window manipulation, display selection, display system navigation).

HSI designs are developed using TA output and the HFE design requirements from the HFE DRD. These design requirements are used to build an HSI style guide and HSI element library. Based on the HSI style guide, display templates and HSI elements such as navigation bars, control faceplates, icons, buttons, and static and dynamic objects are modeled within an HSI design drawing tool. These modeled objects collectively form the HSI element library.

Additionally, style guide conventions are applied to create a User Interface Specification (UIS) assembly of HSI elements in the form of HSI display and panel drawings. Examples include conventions for functional grouping, spacing, flowchart arrow specifications, and system display layouts. Requirements and conventions are provided within the HFE DRD and the HSI style guide, for use in the development of the HSI display and panel drawings. Style flow-downs from the HFE DRD to the HSI style guide and HSI element library are organized into user topical areas. Additional HSI templates and elements are developed and added into the HSI element library as needed (based on input from TA).

The specific displays, panels, and HSI elements designed to support the user tasks are documented in the HSI task support inventory [[

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The HSI design process, described in Section B.3.2.1, is used to create a system's UIS, which contains a [[

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B.3.1 Human-System Interface Design Inputs

The inputs to the HSI design include specific information relating to the performance of tasks, as well as design requirements and guidance specific to the plant design and a defined full set of plant user characteristics. Through an iterative approach, HFE T&E and HFE V&V also provide further input into the HSI design cycle.

The inputs to the HSI design process are summarized in Figure B.3-1 and described in Sections B.3.1.1 through B.3.1.3.

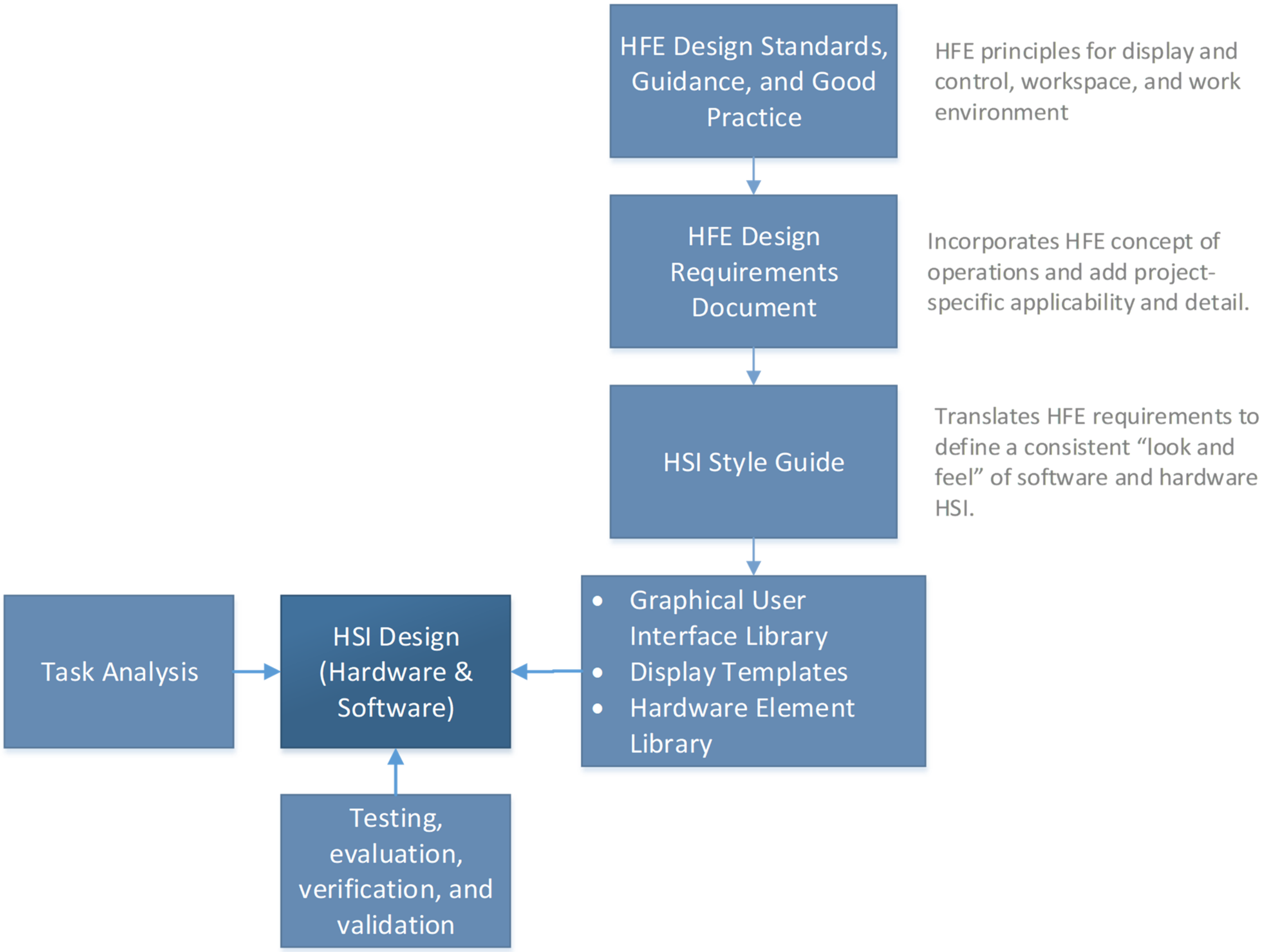

Figure B.3-1: Human-System Interface Design Process

B.3.1.1 Task Analysis Input

A primary input to UIS development is the user task information and control needs established during the TA. The TA provides the following information for the HSI task support inventory:

- Information determining the need for task initiation
- Control needs to accomplish the task steps
- Information feedback to confirm that task step control actions have been accomplished
- Information for determining that task steps accomplished their intended objectives
- Information for determining when tasks may be terminated
- System and component alarms

B.3.1.2 Human-System Interface Design Requirements Input

The second main input to HSI design is the full set of HFE design requirements derived from HF codes, standards, regulations, and best practice guidance. These requirements consider the physical and cognitive characteristics of the standard plant full user population, defined by the HFE COO. The styles (e.g., color, size, font) for software-based UIS implementation are defined in the HFE DRD and the HSI style guide. These style conventions are developed into an HSI element library, which contains HSI display templates, and HSI elements (e.g., symbols, numerical displays, graphs) that the UIS developer uses to assemble the display content. The HSI element library contains both HSI elements for primary interfaces (those that represent direct interface to the system and plant HSI) as well as secondary interfaces (e.g., navigation) which do not directly relate to system equipment. For hardware-based UIS implementation, controls and indicators compliant with HFE design requirements are selected and included in the HSI element library, along with HSI panel templates.

The HFE DRD, the HSI style guide, and the HSI element library are organized by HSI element types for hardware and software. [[

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Requirements are flowed down from the HFE DRD to the HSI style guide for the application of styles in the UIS development. [[

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B.3.1.3 Human Factors Engineering Testing and Evaluation and Verification and Validation Results Input

Throughout the design development, HFE T&E is performed (Section B.4) and later in detailed design, early HFE V&V activities begin. The results from these HFE T&E and V&V activities are ID of HFE issues, discrepancies, or improvement opportunities with the design. Recommended resolutions requiring HSI design improvement form the inputs to further design development.

B.3.2 Human-System Interface Design Process

The HSI design products are created through the interaction and coordination of the HFE team and discipline engineers. The integration of the HFE team with the other disciplines provides the mechanism for designers to request HFE specialist support for instances where it is not clear how the pre-specified requirements are correctly or effectively applied to the HSI design aspect they are implementing. Designers also request support when they identify conflicting design criteria that limit or prevent implementing the HFE design requirements as specified. In such cases, they need HFE specialist advice on the most suitable alternative design solutions.

Degree and type of interaction is based on the risk-based HFE application level as described in the HFEPP (Sections 3 and 7).

For HSIs, the HFE team provides HFE design requirements and task support requirements.

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B.3.2.1 Create User Interface Specification and Data Connection Table

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B.3.2.1.1 Assemble Inputs and Requirements

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Table B.3-1: User Interface Specification Input Gathering Process

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Table B.3-1: User Interface Specification Input Gathering Process

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Table B.3-1: User Interface Specification Input Gathering Process

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B.3.2.1.2 Complete System User Interface Specification for System Deliverable

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Table B.3-2: User Interface Specification and Data Connection Table Creation Process

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Table B.3-2: User Interface Specification and Data Connection Table Creation Process

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Table B.3-2: User Interface Specification and Data Connection Table Creation Process

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B.3.2.1.3 Integrate the User Interface Specification and Data Connection Table

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Table B.3-3: User Interface Specification Integration Process

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B.3.2.2 Test and Evaluation Based Human-System Interface Design Updates

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Table B.3-4: Human Factors Engineering Test and Evaluation Issue Resolution

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B.3.3 Human-System Interface Design Output

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B.4 HUMAN FACTORS ENGINEERING TESTING AND EVALUATION METHODOLOGY

HFE T&E is part of the iterative HSI design process. HFE T&E is the step in which an HSI design concept or prototype is evaluated by a sample of participants who are representative of the HSI end users to evaluate the usability of the design. Usability is determined based on the efficiency, effectiveness, and degree of user satisfaction for the intended population when using the design.

Tests and evaluations are conducted on the HSIs to confirm, refine, or discard design decisions made through analysis and assumptions from the TA and HSI design process, including designs developed by other disciplines or external vendors.

The purpose of HFE T&E is to find and address issues early, rather than waiting for HFE V&V activities near the end of the project. It is a way to test the feasibility of concepts and early prototypes and to facilitate reaching design decisions. Additionally, another difference with the HFE V&V is that the test participants do not exclude design and HFE engineers involved during the design stages.

The scope of the HFE T&E includes:

- Defining the HSI mock-ups, prototypes, emulators, and simulation testbeds
- Defining the HFE T&E team and participants

- Establishing HFE T&E methods for:
    - HSI selection and prioritization
    - HSI evaluation and user-based testing
    - Data collection and analysis

HFE T&E scope ranges in complexity from simple user questionnaire responses and comments to empirical, performance-based techniques to assess how the user responds to the design under increasingly realistic conditions. The level and complexity of HFE T&E is based on design phase, complexity and integration of the design feature to be assessed, and design or project risk (e.g., new use cases for existing HSI technology or First-of-a-Kind (FOAK) systems).

Section B.4.1, B.4.2, and B.4.3 provide a description of the methods and tools used for analyses, reviews, and evaluations of the HSI during the design process.

Tests are divided into two main categories:

1. Display and panel design testing – Involves the testing of the static and dynamic features of any kind of HSI
2. Work environment (layout and workstation) testing – Involves the testing of the physical aspects of the workstation design, including anthropometric measures and movement patterns within the workspace

B.4.1 Human-System Interface Prototypes and Testbeds

HSI evaluation and user testing is an integral and iterative part of the design process, with the results of each phase being used to adjust the design as necessary to meet HFE requirements and goals.

To be efficient in terms of time and resources, and to support iterative design development and refinement, it is necessary to employ multiple evaluation tools and testbeds based upon the test category, design maturity, the HSI features to be tested, and the test objectives.

Evaluation methods include the following:

- Paper-based checks using drawings to evaluate static design features (e.g., dimensions, layouts, labeling, access) – suitable for display and panel static features, layout, and workstation checks
- 3D model mannequin interactions with HSIs to evaluate physical characteristics of the work environment suitable for layout and workstation checks
- Walk throughs using physical mock-ups – suitable for layout and workstation checks
- I/O point stimulation and emulation – suitable for evaluation of simple display and panel dynamic features (e.g., component status color changes) and presenting complex dynamic HSI configurations not naturally resulting from the simulator model to test for potential error traps and cognitive overload
- Part-task simulation – suitable for display and panel static and dynamic features, layout, and workstation checks
- Full-scope simulation – suitable for display and panel static and dynamic features, layout, and workstation checks

B.4.1.1 Two Dimensional Drawings

Drawings are used to perform preliminary user checks to ensure design assumptions or design concepts are viable. Drawings are presented to gain early user feedback on initial design concepts.

HSI drawings include:

- Hardware panels
- Workspace layouts
- Console design
- Panel arrangement
- Software displays

The results of a typical paper-based evaluation include a list of HFE issues identified and recommendations for modifying the design to resolve the issues.

In order to expand the scope of a paper evaluation to include understandability and effectiveness considerations, the team carefully analyzes the design to ensure information requirements and design function objectives are satisfied. The paper-based evaluations of usability are performed using criteria and guidance from the HFE DRD.

Both the electronic and paper-based evaluation methods are used in either static or dynamic evaluation processes. When used statically, the images (either on paper or electronic screen) are examined from an HF perspective. When used dynamically, the images are used in a talk-through process to verbalize what is expected to appear in a specified event, and to examine this from an HF perspective. These HFE evaluations are facilitated using the checklists in Section B.6.1 and Section B.6.2.

B.4.1.2 Three Dimensional Renderings and Mock-ups

Mock-ups are constructed and used as tools in the development of the HSI to evaluate the system design before the actual manufacture of system hardware. Mock-ups provide a basis for resolving access, workspace, and related human engineering issues, and incorporating these solutions into HSI design.

3D virtual mock-ups are used to make ergonomic assessments of general console and panel shape. Virtual 3D tools are used to check room layouts and panel designs regarding ergonomic assessments of:

- Sightlines
- Reach radii
- Foot and knee clearances
- Physical access and clearances

3D virtual mannequins - virtual representations of humans in changeable (e.g., sitting and standing) positions created based on 5th and 95th percentile user anthropometric data, as defined in the HFE COO - are used to facilitate ergonomic assessment by allowing the user or

HFE T&E team to position the virtual humans within the 3D layout according to task requirements.

B.4.1.3 Emulation and Simulation

The primary objective of emulation and simulation based HFE evaluation is to provide a more interactive and realistic representation of the HSIs to better assess usability of the HSI design. As discussed earlier, this involves determining whether users can comprehend the messages transmitted to them by the system, and whether they can communicate their needs back to the system.

The purpose of evaluating understandability is to assess the validity of the answers generated during design by answering the following questions:

- Do users comprehend the messages presented by the system?
- Was a complete amount of information given to the user for the current situation/issue?
- Do users correctly formulate responses to these messages?
- Do users correctly communicate their responses to the system?

Dynamic emulation and simulation techniques are used by the HFE team as a human engineering design tool for the detailed design of equipment requiring critical human performance. Consideration is given to use of various models for the human user, as well as person-in-the-loop simulation. The simulation equipment is intended for use as a design tool, although its use as training equipment is considered in any plan for dynamic simulation. As such, the HFE team also use emulators for targeted design, as well as person-in-the-loop, lower fidelity simulation testing as a precursor and parallel testing method to the full-scale simulator.

During the design phase, a simulation engine is used to provide a representation of the operation and responses of the plant. A generic plant simulation model is used by the HFE team on a computer workstation-based platform or glass-top based platform (as available) for HSI development and HFE T&E.

Once site-specific system models become available, tests and evaluations are conducted using the site-specific models instead. Intermediate phases are referred to as a part-task simulator. The part-task simulator is run on computer-based workstations containing VDUs and input devices (i.e., mouse and keyboard) to demonstrate display and panel design and functionality.

The computer workstation-based simulation platform is used by the HFE team for the development and testing of HSI display and panel designs, and the initial development and testing of the plant normal, abnormal, and emergency operating procedures.

To increase platform fidelity, the computer workstation-based simulation platform is integrated into a mock-up. Mock-ups can use a glass-top simulation platform implemented with programmable displays and touch screens, which are configured to represent hardware-based panels, having hardware-based controls and indications active so that the user can use the hardware-based controls and observe the hardware-based indications. Integration of the computer workstation-based simulation platform into the mock-up allows the HFE team to conduct more complete walk-through HSI assessments, as this configuration provides the hardware and software-based controls and indications needed to perform user tasks.

Additional fidelity is added with the availability of the full-scope simulator, which contains the simulation models for the plant systems included in the detailed system design and allows for simulation of normal, abnormal, and emergency plant operations.

B.4.2 Human Factors Engineering Testing and Evaluation Team Composition

B.4.2.1 Test Personnel

The HFE T&E team size varies in relation to test scope and type of testing. Recommended team minimum composition is as follows:

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The HFE T&E team owns the test responsibility and interfaces with other disciplines and HFE activity owners for the following:

- Determining, and mutually agreeing on, the readiness of an HSI for testing. Readiness is dictated by factors such as design selection and availability, project resources, and test platform availability
- Preparing test plans that cover objectives, conditions, methods, participant demographics, measures, and acceptance criteria
- Coordinating test requests, arrangements and preparations, and schedules
- Conducting tests
- Preparing test reports
- Initiating follow-through on recommendations and resolution of issues. Findings and resolutions to test anomalies are a basis for HSI design refinement and corrections.

B.4.2.2 Test Participants

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]]$^{(a)(4)}$ Test participants are representative of the user population as defined by the HFE COO. Tests include users from various project-specific customers as much as practicable.

B.4.3 Methods

B.4.3.1 Human-System Interface Selection and Prioritization

Selection and prioritization of the HSI design products are based on the risk-based HFE application level as described in the HFEPP (Sections 3 and 7):

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Beyond this grading, additional HSI are selected for HFE T&E inclusion based on the following considerations.

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Table B.4-1: Human-System Interface Selection and Prioritization Criteria

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B.4.3.2 Human Interface System Evaluation and User-Based Testing

Evaluation methods during HSI design use HF evaluations, trade-off evaluations, and performance-based testing protocols. Trade-off evaluations are used to assess design alternatives against one another or an existing baseline, based on feedback from users and HFE evaluation. Performance-based testing is used to determine the acceptability of a design to support user task performance. Performance-based testing may also be used to provide data to support trade-off evaluations involving criteria such as errors or task performance time.

B.4.3.2.1 Human Factors Evaluation

An HFE evaluation uses checklists in Section B.6.1 and Section B.6.2 and HFE subject matter expertise to evaluate the HSI design and determine if it is compliant to the HFE DRD and if it meets HFE relevant good practice.

B.4.3.2.2 Trade-Off Evaluation

Trade-off evaluations (Section B.6.3) are conducted among the following stakeholders: HFE, HSI designers, samples of end users, and the customer. The following steps are used to identify to conduct trade-off evaluations:

1. Select trade-off study key criteria (e.g., the criteria listed here). [[

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2. Place the selected key criteria and the design alternatives to be evaluated in a Pugh Matrix trade-off tool.

3. Establish importance ratings for key criteria – importance ratings range from 1 to 10, (10 being better) for use as a multiplier of the better and worse rankings of alternatives.
4. Evaluate each alternative against the key criteria (i.e., +, same, -) relative to benchmark option. Benchmark option gets “S” (same) scores on all criteria.
5. Calculate total score = weighted sum of positives minus weighted sum of negatives for each alternative.
6. Use results of the Pugh Matrix as a basis to make the HSI design alternative trade-off decision. If there are several closely ranking sums, further HFE review or analysis may be needed.
7. Record and track the HF issues resulting from this evaluation using the HFEITS as described in Section 6.4 and Section 8. Issues that cannot be resolved within the design phase timeframe include the necessary information to address them in future project stages.

B.4.3.2.3 Performance-Based User Testing

Performance-based testing consists of observing users interacting with the HSI design, given a goal to reach. Members of the test team observe the user’s actions without intervening and record what transpires. Post-test analysis focuses on any difficulties encountered by the user, illustrating differences between the design team’s assumptions and actual user behavior.

1. As the first step to conducting performance-based testing, prepare a test plan that includes the following, as applicable:
    a. Purpose
    b. Equipment needed/testbed
    c. HSI design features to test
    d. Test methods
    e. Measures and acceptance criteria
    f. Data collection method
    g. Constraints
    h. Test schedule
    i. Event guide
2. Select performance measure(s) and establish the test design by completing the form in Section B.6.4.
3. Detail the design features selected for user testing.
4. Select a testbed considering the design features to be tested, in conjunction with the maturity of the design:
    a. Availability of plant modeling software and integrated HSI design status

   b. Availability and fidelity of a mock-up
   c. Availability of control area and equipment 3D modeling
   d. Availability of procedures, procedure types, and training material

5. Set acceptance criteria for design acceptability and basis/justification for selected criteria.

6. Select participant population pool (Section B.4.2.2) for evaluation and document on the form in Section B.6.4. Ensure the population pool is sufficiently diverse and representative of the user population.

7. Choose sample size for evaluation and add to the HFE performance test methods and measures form. Performance-based evaluations include usability tests, interactive design development evaluations, and design development tests. For usability testing and interactive design development evaluations, the sample size consists of approximately five participants. This allows for more testing with fewer participants during development. More participants may be chosen when testing performance between multiple options or when performance is close to a requirement threshold.

8. Develop an observation and evaluation plan. The observation plan includes written test plans, scripts for observers and evaluators, standardized training for participants, and the same observers or proctors for all runs of an evaluation whenever possible.

   During design development, the performance-based testing may be formative in nature. This type of testing allows for quick prototyping and issue resolution. [[

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   At appropriate points in the detailed design, testing is done with a summative approach. [[

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9. Perform evaluation and record observations.

B.4.3.3 Data Collection and Analysis

This section provides a description of the methods and tools used for analyses, reviews, and evaluations of the HSI during the design process.

Techniques appropriate for the evaluation of HSI include, but are not limited to:

- Participant questionnaires and interviews
- Direct observation of user behaviors (e.g., task time, task errors, HSI interaction or navigation errors)
- Emulator or simulator data recordings

The following are criteria used in selecting HFE techniques:

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The design evaluation is based on the objectives of the systems design:

- What does the system do?
- Who uses it?
- Where is it used?
- When is it used?

If the objectives are clear, the evaluation of the results is made simpler. Numerous methods are available for evaluation of designs.

Questionnaires, interviews, observations, and the instructor console are used, as described in Sections B.4.3.3.1 to B.4.3.3.4, to gather HSI tests and evaluations data and information.

B.4.3.3.1 Questionnaires and Interviews

Paper-based user evaluation methods, such as questionnaires, are used in either a static or dynamic evaluation process. When used statically, the images (either on paper or electronic screen) are examined by users from an HF perspective. When used dynamically, the images are used in a walk-through/talk-through process with users to verbalize what is expected to appear in a specified event and to examine this from an HF perspective.

The questionnaire is a subjective measurement tool for systematically obtaining attitudinal responses from a selected group of individuals. The questionnaire provides a structured method for asking a series of questions to obtain measurable expressions of attitudes, preferences, and opinions. The questionnaire is used to assess a wide variety of qualitative variables such as acceptance, ease of use and preference. Questionnaires are used for obtaining information about positive system features and system issues that have been noted during evaluations. An example of a questionnaire is provided in the form in Section B.6.5.

The interview technique is the process of the evaluator discussing the test events with the participants. The purpose of an interview is to find out either objective facts related to the system about which the interviewee has some knowledge, or subjective information, attitudes, or opinions about how they feel about some test aspect.

B.4.3.3.2 Observation Forms

HFE test observers use an observation form that includes fields to properly annotate the findings. An example of an HFE observation form is provided in Section B.6.6.

B.4.3.3.3 Recordings

Video and data recorded during the test sessions is used by the HFE team for analysis. [[

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B.4.3.3.4 Analysis of Results, Documentation, and Treatment of Human Factor Engineering Issues

After all user feedback has been obtained, from providing inputs to trade-off analysis and participating in performance-based user testing, the HFE T&E team analyzes the data, identifies issues, enters issues into HFEITS, and prepares a T&E report. The report contains a summary of data and findings, as well as recommendations regarding potential resolutions (e.g., modifications to HSIs or user training) that may have been identified in test observations or follow-up analyses. The HFE T&E team ensures the report is distributed to affected disciplines.

B.5 TASK ANALYSIS AND HUMAN-SYSTEM INTERFACE DESIGN WORKBOOK TEMPLATES

B.5.1 Task Step Sequence Narrative Template

Figure B.5-1 shows an example of a task step sequence narrative template.

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Figure B.5-1: Task Step Sequence Narrative Template

B.5.2 Task-Level Support, Job Design, Workload, and Workplace Block Template

Figure B.5-2 shows an example of a task-level support, job design, workload, and workplace block template.

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Figure B.5-2: Task-Level Support, Job Design, Workload, and Workplace Block Template

B.5.3 Human-System Interface Task Support Inventory Template

Figure B.5-3 shows an example of an HSI task support inventory template.

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Figure B.5-3: Human-System Interface Task Support Inventory Template

B.5.4 User Interface Specification – Data Connection Table Template

Figure B.5-4 shows an example of a user interface specification DCT template.

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Figure B.5-4: User Interface Specification – Data Connection Table Template

B.6 HUMAN FACTORS ENGINEERING TESTING AND EVALUATION FORMS

B.6.1 Human Factors Design Evaluation Checklist

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B.6.1.1 Software-Based Human-System Interface Element Library

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B.6.1.2 Software-Based Human-System Interface Displays

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B.6.1.3 Hardware-Based Human-System Interface

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B.6.1.4 Workstation and Panel Configurations

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B.6.2 Human Factors Task Support Evaluation Checklist

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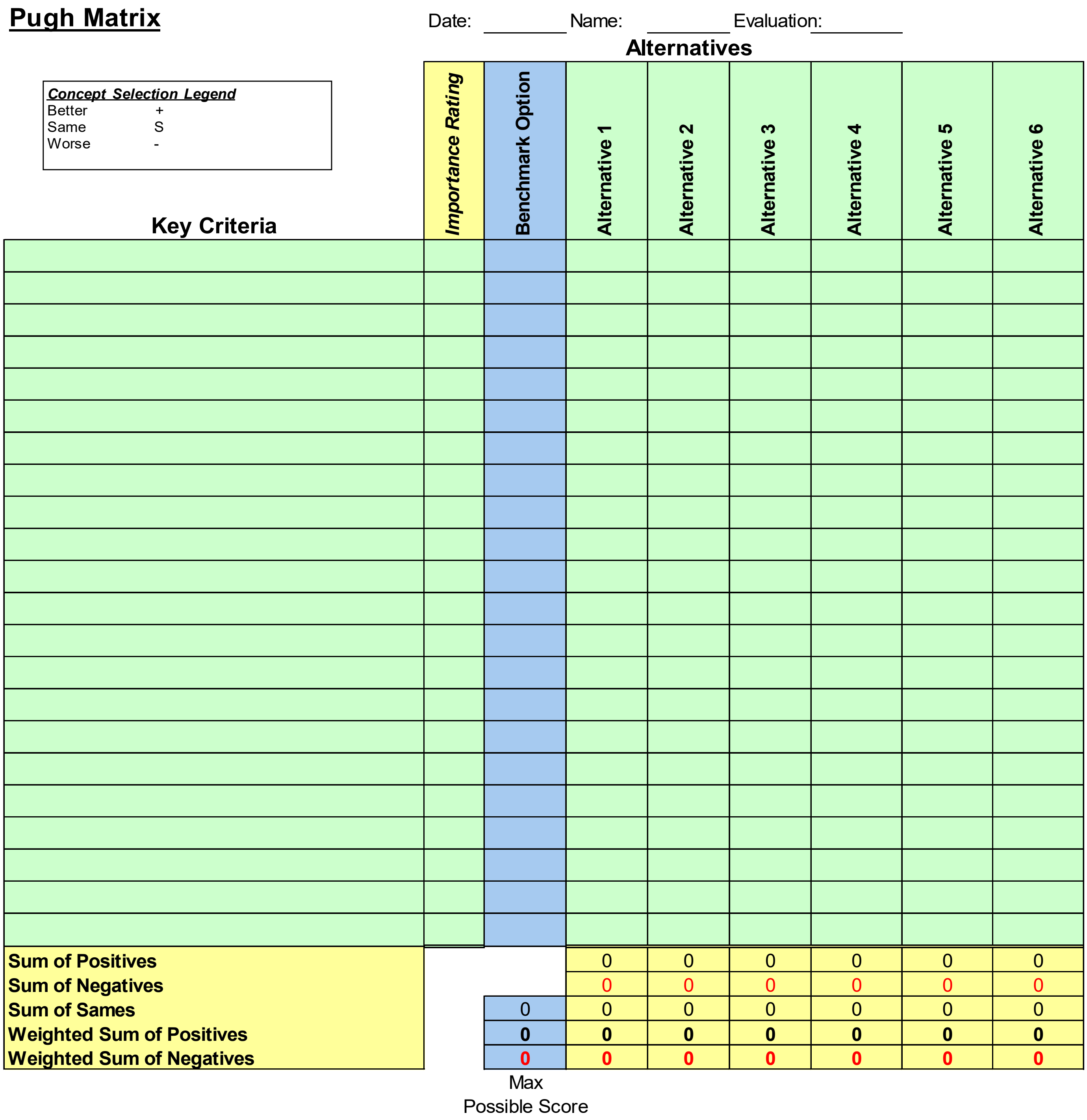
B.6.3 Trade-Off Evaluation Form

Figure B.6-1 is an example of a trade-off evaluation form (Pugh Matrix). When completing a form, the performer includes their full name and the date that the evaluation was performed on each page of the documentation.



Pugh Matrix

Date: ________ Name: ________ Evaluation:________

Concept Selection Legend

Better	+
Same	S
Worse	-

Alternatives

Key Criteria	***Importance Rating***	**Benchmark Option**	**Alternative 1**	**Alternative 2**	**Alternative 3**	**Alternative 4**	**Alternative 5**	**Alternative 6**
Sum of Positives			0	0	0	0	0	0
Sum of Negatives			0	0	0	0	0	0
Sum of Sames		0	0	0	0	0	0	0
Weighted Sum of Positives		**0**	**0**	**0**	**0**	**0**	**0**	**0**
Weighted Sum of Negatives		**0**	**0**	**0**	**0**	**0**	**0**	**0**
		Max Possible Score						

Figure B.6-1: Trade-Off Evaluation Form

B.6.4 HFE Performance Test Methods and Measures Form

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B.6.5 Usability Questionnaire Form

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[[

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B.6.6 Human Factors Engineer Observation Form

The following is an example of an HFE observation form.

HFE Observer Name: ________________ Date: __________ Evaluation: _____________

#	Step or Action	Time	Observation/Comment

Appendix C: Human Factors Engineering Staffing Analysis Plan

C.1 INTRODUCTION

The staffing analysis presented in this appendix is one of the elements of the HFEPP. The systematic staffing analysis determines the minimum staffing levels to ensure safety is maintained. The staffing analysis is done in stages and is iterative as the project progresses, with staffing levels subject to evaluation and modification in conjunction with related HFE and wider project design activities.

C.1.1 Scope

The staffing analysis is conducted to determine the minimum staff complement. The project minimum staff complement is defined as the minimum number of workers with specific qualifications who are always available to the site. The minimum staff must be able to successfully respond to all credible events for any plant state. Credible events are those within the plant design basis and [[

]]$^{(a)(4)}$ For staffing assumptions where minimum staff may be varied for different operational states, the most resource-intensive events for each plant mode are analyzed.

The staffing analysis determines the staffing limits in collaborative facilities such as control rooms. This informs the needed space, facilities, and other support features.

C.2 REQUIREMENTS AND TECHNICAL BASIS

This section contains the process requirements and technical basis inputs applicable to the creation, implementation, and maintenance of the staffing plan, by way of staffing analysis.

The staffing plan is compliant with the requirements included in Section 5.4 and considers best practices from IEEE 1023-2020 (Reference 2) and NUREG-0711 (Reference 3).

C.3 STAFFING ANALYSIS OVERVIEW

The staffing analysis is integrated with and informs other technical elements of HFE design.

The staffing analysis takes place in three major steps:

- Expert panel staffing assessment
- Staffing analysis in TA and HSI design process
- Staffing analysis in the HFE V&V process

Figure C.3-1 outlines the steps for the systematic process.

The staffing analysis begins by using the manning assumptions in the HFE COO and is then informed by relevant OE.

Using this information, the staffing is optimized, considering the design of the project. The assumed staffing levels are subject to an expert panel staffing assessment that evaluates the staffing to analyze selected credible events.

The next steps are in conjunction with the TA and HSI design process. During TA, task steps are defined, and personnel assignments are made. The TA forms the basis for job design and qualifications for each role. With TA, timeline analysis is conducted for the most resource-intensive credible events. These events are selected by the expert panel, and the expert panel also performs a review of the timeline analysis and input TA data to evaluate whether the staff complement is adequate to effectively respond to events.

Subsequently, scenarios for a wider range of events are created and analyzed in the T&E phase of the TA and HSI design process. This allows further evaluation of the staffing complement against the most challenging credible events. HSI tests evaluate, using platforms and mockups that replicate the interface design, the timing of activities, workload (physical and cognitive), and other factors such as situation awareness that may lead to changes in the staff complement and job design.

In the next stage, the staff complement baseline is evaluated through the HFE V&V activities. This occurs during the ISV where ISV demonstrates the adequacy of the final staffing levels that are results from the analyses.

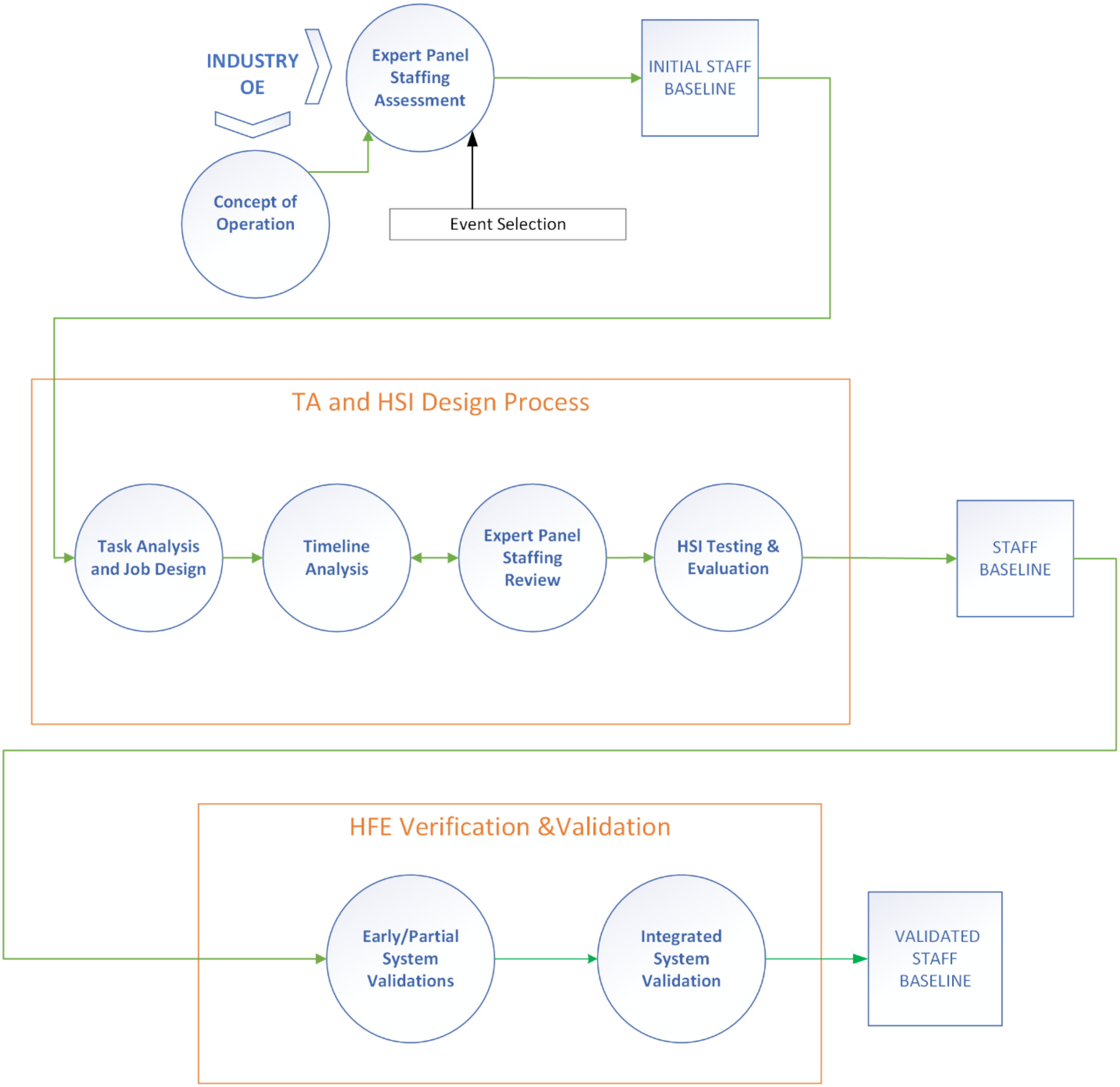

Figure C.3-1: Staffing Analysis Overall Process

C.4 INPUTS

The staffing analysis uses input information from the following documents and activities:

- Operating Experience Review – The design considers OE lessons learned from predecessor designs. HFE focuses on the specific OEs related to human performance issues. Industry OE is incorporated into the staffing analysis through the initial staffing assumptions in the COO and the expert panel staffing assessment.
- Concept of Operation – The COO describes the ways in which users interact with the HSIs and with each other to safely operate the plant. The document includes the initial staffing assumption and role descriptions that are inputs to the staffing analysis process.
- Allocation of Function – The number of staff and their qualifications is influenced by the functions and tasks allocated to human, or to shared responsibilities between human and machine. A modification of the functional allocation during the design process may affect the staffing and job design and requires evaluation.
- Task Analysis – The TA process assigns a performer for each task step and identifies all plant personnel involved to complete a task. TA provides the required data to perform timeline analysis and the expert panel staffing review.
- [[

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C.5 METHODOLOGY

The methodology starts with the staffing assumptions from the COO. Staffing is adjusted based on the project design aspects and features, and is assessed and tested by following the steps and as shown in Figure C.3-1:

1. Expert panel staffing assessment
2. Staffing analysis in TA and HSI design
    a. TA and job design
    b. Timeline analysis
    c. Expert panel staffing review
    d. HSI T&E
3. Staffing analysis in the HFE V&V process
    a. Validation (early/partial system validations and ISV)

The TA and HSI design processes are described in Appendix B of this report and V&V design processes are described in Appendix D of this report.

C.5.1 Expert Panel Staffing Assessment

The first step in the staffing analysis is an expert panel assessment. The goal is to perform early and iterative assessments as the design progresses so that the risk of inadequate staffing is reduced with each evaluation.

The expert panel is made up of personnel from the [[ ]]$^{(a)(4)}$

C.5.1.1 Pre-Job Briefing

Before each assessment by the expert panel, a pre-job briefing is held to review the goals, inputs, and methodology used. During these briefings, input is solicited from the expert panel on the events analyzed for minimum staff complement assessment.

C.5.1.2 Event Selection

The expert panel follows a selection process determining the events for analysis. The process uses a bounding approach, selecting the most resource-limiting events across the entire list of possible credible events. [[ ]]$^{(a)(4)}$ Each iteration of the staffing analysis takes into consideration the latest safety and HFE analysis outcomes that identify postulated initiating events and event sequences that require HAs.

C.5.1.3 Event Analysis

The event analysis describes the initial plant condition and event initiator. The event progression is on a timeline that describes each task, the role that performs the task, and the time duration for each task. An example timeline analysis format is provided in Table C.7-1. The roles are based upon those assumed in the COO. However, roles may be added if needed to support acceptable performance for the event.

Tasks considered for the analysis are:

- Manual actions
- Plant monitoring
- Oversight and command and control
- Relocations or transit times (if not considered as part of the manual actions)
- Communications or notifications
- Procedure execution

Considerations for the analysis are as follows:

- [[ ]]$^{(a)(4)}$
- Available design documentation such as arrangement drawings, system diagrams, and system design description should be used to support the analysis
- The analysis is based on engineering judgement of realistic performance estimates

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For each task on the timeline, the following additional information is recorded:

- [[
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C.5.1.4 Event Assessment

The expert panel reviews the event progression timeline and task details assessing whether the sequence is completely and accurately described. The expert panel also assesses whether the task timing is reasonable based on their judgement. Any comments from the expert panel are recorded and resolved prior to finalizing the assessment. The final assessment is documented in an expert panel staffing assessment report.

C.5.2 Staffing Analysis in the Task Analysis and Human-System Interface Design Process

The TA and HSI design processes are described in Appendix B. These processes support the more detailed staffing analysis discussed in Section C.5.3.

C.5.2.1 Task Analysis and Job Design

The TA process is informed by the task ID and HFE application level from the AOF and task grading results discussed in Appendix A. These tasks undergo task step sequence narrative defining the task. This definition includes a step-by-step evaluation of the task actions, performers, and location. The performers are initially selected based on staffing specified in the COO. The task definition also includes timing estimates for the task as a whole and at the step level when needed.

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C.5.2.2 Timeline Analysis

An update to the timeline analysis used in the early event analysis is completed in conjunction with TA and HSI design incorporating more of the detailed TA results and insights into the analysis.

Before the update to the timeline analysis, a pre-job briefing is held describing the goals, inputs, and methodology used. During the briefing, the events analyzed from the early event analysis are also reviewed by the expert panel. Attention is given to the need to add or remove events from consideration based on expert panel concurrence. An example table for completing this review is provided in Table C.5-1. Once identified, this group of events becomes the event list for staffing analysis during T&E and V&V.

Table C.5-1: Event List for Staffing Analysis

#	Title	Description	Initial Plant Conditions	Notes

Notes:

1. # is the event sequencing number
2. Title is the event name
3. Description is a brief narrative about the scenario
4. Initial plant conditions are the plant conditions just before the event

C.5.2.3 Expert Panel Review

The expert panel is made up of personnel from the [[

]]$^{(a)(4)}$. The expert panel reviews the event progression timeline and task details from the TA assessing if the sequence is completely and accurately described. The expert panel also assesses whether the task timing is reasonable based on their judgement. Any comments from the expert panel are recorded and resolved prior to finalizing the assessment. The final assessment is documented in an expert panel staffing review report.

C.5.2.4 Human-System Interface Test and Evaluation

The HSI T&E design process is described in Section 5.7.6. HFE T&E is part of the iterative HSI development and rapid prototyping process where the HSI design concept or prototype is evaluated by a sample of participants who are representative of the HSI end-users.

The purpose of the HFE T&E is to find and resolve issues before the HFE V&V activities. Issues regarding staffing levels, job design, and qualifications may require changes in the previous analysis.

The staffing analysis relies on T&E for performance-based testing of the most resource-intensive credible events on the event list for staffing analysis that identified and reviewed through the previous expert panel assessments and expert panel reviews. The T&E process governs any tradeoff analysis required to resolve issues related to the design and staffing and informs the respective HFE elements.

C.5.3 Staffing Analysis in the Human Factors Engineering Verification and Validation Process

The project HFE V&V process is described in Appendix D. This V&V process uses a multiphase validation approach. The early validation including partial system validations are performed as the design matures and tools are available for testing. This allows for the ID of issues prior to ISV.

Staffing levels are checked iteratively throughout the whole HFE process prior to ISV. For ISV, the event list for staffing analysis is included in the scenarios for sampling of operational conditions. The final objective of ISV is to ensure that the integrated system, including the staff, satisfies its designed functions. Control means, procedures, system design, involved personnel, and the environment provide the operators with what is needed to safely operate the plant and eliminate or mitigate the effects of human error.

ISV scope includes:

- The role of plant personnel
- Shift staffing, assignment of tasks to crew members, and crew coordination are acceptable
    - This includes validation of nominal shift levels, minimal shift levels, and shift turnover
- Specific personnel tasks are accomplished within time and performance criteria, with a high degree of operating crew situation awareness, and with acceptable workload levels that balances vigilance and operator burden

The output of the ISV is the validated minimum staff that can respond effectively to the most resource-intensive credible events. Any issues that are observed are tracked and dispositioned with the HFEITS described in Section 6.4.

C.6 DOCUMENTATION

The following documents are prepared with the specific purpose of recording staffing analysis results:

- Expert Panel Staffing Assessment Report – A report is created for each expert panel staffing assessment documenting the scope and results.
- Expert Panel Staffing Review Report – A report is created for the expert panel staffing review documenting the scope and results.

In addition to these reports, outputs and reports are created for the HFE TA, HSI, and V&V processes.

C.7 EXAMPLE TIMELINE ANALYSIS FORMAT

Table C.7-1: Example Timeline Analysis Format

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Table Key:

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Appendix D: Human Factors Engineering Verification and Validation Plan

D.1 Introduction

D.1.1 Purpose

The HFE V&V Plan is a part of the overall HFE process defined in this topical report. The HFE V&V plan evaluates the design of individual SSCs and the design as an integrated whole against HFE design principles and user task requirements.

The HFE V&V plan establishes the V&V processes and presents the methods, criteria, and tools to develop them. In addition, this plan provides the resources for performing activities that support efforts like operational conditions sampling and HED ID and resolution.

The HFE V&V is conducted in two major activities: verification and validation.

Verification is the process by which the design is evaluated against task requirements (TSV) and conformance to the HFE design requirements (design verification).

Validation proves that the design accomplishes its intended goals and functions in a simulated operational environment (ISV). Ultimately, the validation confirms that the design allows the operations staff to operate the plant safely and successfully, performing the necessary tasks to meet safety and operational requirements and acceptance criteria.

The HFE V&V process consists of an iterative cycle between each V&V activity and the HFE analysis and design (task and HSI process). HSIs and tasks go through a sampling process to select and focus on those that are most risk significant. Additional detail regarding the sampling process is provided in Section D.4. These selected HSIs, tasks, and scenarios are verified and validated. Finally, the results, recommendations, and corrective actions derived from identified HEDs are incorporated back into the analysis and HSI design until HFE V&V acceptance criteria are met.

Figure D.1-1 illustrates the iterative nature of the HFE V&V process. Figure D.10-1 provides a more detailed diagram of the HFE V&V process.

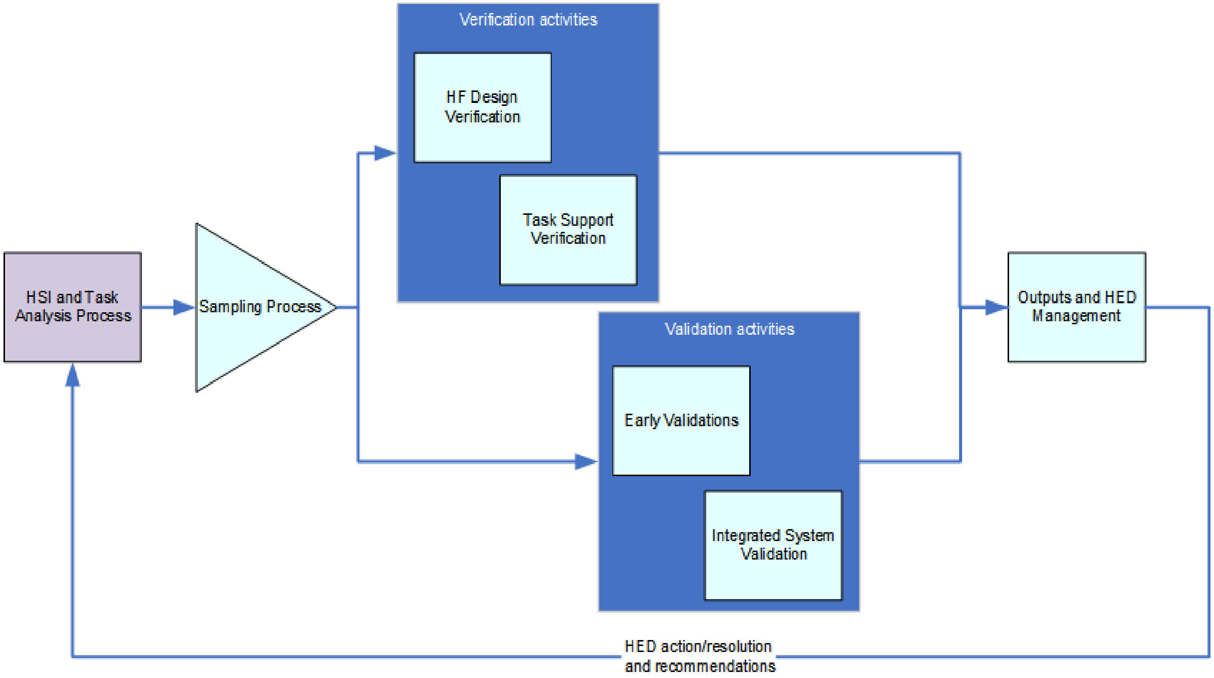

Figure D.1-1: Human Factors Engineering Verification and Validation Process Overview

The HFE V&V activities use multiple, diverse evaluation tools and testbeds. In the case of the verification, software drawings and images are used to verify static design features, and simulation tools are used to verify dynamic features. In the case of the validation, physical mockups, 3D virtual mockups, part-task simulators, and full-scope simulators are used to carry out the HFE activities.

D.1.2 Scope

The HFE V&V process applies to the following functions and tasks:

- Functions and tasks that support functional requirements and require human or machine with human support to execute (non-passive).
- Tasks done within NI plant systems, including maintenance items that are accomplished throughout the NI.

The HFE V&V process applies to HSIs included at the following locations on the NI:

- NCR
- RSF
- Local controls

The HFE V&V process also applies to HSIs included at the following local field interfaces that support NI-related aspects of the plant:

- Operations
- Plant safety and protection systems
- Maintenance, decommissioning, and refueling

The scope of HFE design covered during HFE V&V includes the following:

- Automated features and processes
- Task requirements and job design
- Staffing
- Training and qualifications
- Crew communications
- Operation aids
- Hardware and software-based HSIs (e.g., alarms, controls, and indications) used for normal, abnormal, and emergency operations, maintenance, test, inspection, and calibration
- Information architecture and navigation schema
- Layout/configuration and ergonomics of workstations and panels
- Work environment (e.g., lighting, space, air conditions, floor design, noise mitigation)
- Procedures
- Provisions for routine tests and maintenance (e.g., cleaning touchscreen displays, testing alarms, and other similar activities)

As discussed in Section D.3, the application of HFE V&V to the phase and location scopes is also graded to focus on the HSIs and operational conditions that involve important human interactions that are safety critical or hazardous. The same risk-based approach described in the HFEPP is applied to the HFE V&V sampling of operational conditions. This is further detailed in Section D.4.

The HFE V&V process includes the following areas:

- Sampling of operational conditions (Section D.4)
- HFE verification (Section D.5)
- TSV
- HFE design verification
- HFE validation (Section D.6)
- HED management (Section D.7)

D.2 Roles and Responsibilities

D.2.1 Human Factors Engineering Verification and Validation Team Roles

The HFE V&V team consists of a technical lead and an experienced team of HF engineers qualified to develop and conduct HFE V&V activities.

The HFE V&V technical lead may be the same individual defined in Section 4.1.1. However, the HF engineers performing HFE V&V activities must be different engineers from the ones involved in the design process to ensure HFE V&V activities are conducted independently and free from bias.

In addition to the qualifications specified in the HFEPP for HF engineers, Table D.2-1 delineates additional qualifications and responsibilities specific to HFE V&V:

Table D.2-1: HFE V&V Team Contributions and Qualifications

Role	Contributions	Qualifications
HFE V&V Technical Lead	Same as defined in Section 4.1.1.	Same as defined in Section 4.1.1.
HFE V&V Engineer	• Provide knowledge of human performance capabilities and limitations, applicable HF design and evaluation practices, and HF principles, guidelines, and standards • Develop and perform HFE V&V activities • Participate in the resolution of HEDs • HFE sub-specialties include cognitive science, ergonomics, HSI, and testing/experimental design	• Bachelor’s degree in HFE, engineering psychology, or related science • Four years cumulative experience related to the HF aspects of human-computer interfaces o Qualifying experience includes at least the following activities within the context of large-scale human-machine systems (e.g., process control): design verification, TSV, and ISV • Four years of cumulative experience related to the HF aspects of workplace design o Qualifying experience includes at least participation in previous HFE V&V activities from new plants or plant modifications

D.2.2 Human Factors Engineering Verification and Validation Team Responsibilities

The responsibilities of the HFE V&V team are to establish and perform the activities defined in this plan. The HFE V&V team’s specific duties are to guide and oversee the V&V activities and ensure the execution and documentation is carried out in accordance with the established program and procedures.

D.3 Graded Approach and Risk Level Determination

A graded approach based in a risk level determination is applied to the project as discussed in Section 3.

Three levels of HFE application result from the risk determination. Application Level 1 comprises the HAs with high risk from the combined perspective of the nuclear safety, personnel safety, and asset protection, Application Level 2 is associated with a medium risk, and Application Level 3 poses minimum risk.

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D.4 Sampling of Operational Conditions

The sampling of operational conditions process establishes the scope of the HFE V&V activities. In a new plant design, the number of scenarios and HSIs is large, so this process focuses on improving the efficiency of the HFE V&V activities and avoiding unnecessary efforts.

Through the sampling process, the inputs that bound the scope of the HFE V&V activities are selected. The verification activities target a selection of HSIs (e.g., displays, panel layouts) and the validation activities target a selection of scenarios.

The goal of sampling is to maximize sample relevance and significance while ensuring that the sample is broad and diverse, so that the HFE V&V results are generalizable to the overall population of HSIs and scenarios.

D.4.1 Task Analysis Graded Approach Output Information

The sampling strategy starts from the graded approach based on a risk level determination and refinement during the TA and HSI design process.

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D.4.2 Minimum Sample Conditions

The following list of minimum conditions expands the scope beyond the graded approach based on risk level by also considering a wide range of operations that cover different types of failures, procedures, and environments. These minimums ensure that an essential set of operational conditions is covered.

The minimum sample includes:

1. [[

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D.4.3 Representative Population Sampling

In addition to the minimum sample conditions delineated in Section D.4.2, to ensure a sufficiently broad set of HSIs and conditions are included, the following items are also represented in the sample list:

1. Plant control (apart from the scenarios already listed in the minimum list)
    a. Additional risk-important scenarios within the scope of the EOPs and SAMGs
    b. License basis document abnormal operational occurrences, including time dependent actions, as applicable
    c. Additional risk-important abnormal events and transients within the scope of AOPs
    d. Additional risk-important equipment degradations and failures within the scope of alarm response procedures

    e. Additional risk-important events involving more than one control and monitoring location

2. Personnel tasks
    a. Historically problematic tasks as identified in the HFE OER
    b. Procedures from each class used in the operation of the plant including administrative, emergency, abnormal, alarm response, general operating, system operating, surveillance and testing, maintenance, chemistry control, and radiation control
    c. [[ ]]$^{(a)(4)}$
3. Tasks representing a broad range of human cognitive activities – tasks identified as containing the following attributes as in the response requirements portion of detailed TA:
    a. Detection and monitoring
    b. Diagnosis and situation assessment
    c. Decision-making and planning
    d. Plant manipulation
    e. Monitoring plant response
4. Tasks involving a range of human interactions and communications as identified in the TA – tasks identified as containing communication interactions between the primary task performer and other personnel
5. Tasks performed with high frequency as identified in the TA – tasks identified as having high repetition in the response requirements portion of TA
6. Situational factors
    a. Operationally difficult tasks as identified in the HFE OER
    b. Scenarios specifically designed to generate human errors (e.g., failure of an automatic start signal to initiate) (this allows evaluation of error tolerance and error recovery)
    c. Scenarios performed with varying crew sizes – variance between minimum and nominal crew size as defined in the HFE COO
    d. Instances of high and low workload as identified in the TA – tasks identified as high workload in the workload determination portion of the TA
    e. Instances of varying workload – tasks in this area can vary by their nature (e.g., a scram during normal operations, or the cessation of work following the shutdown of a system the crew is controlling) or may vary due to sequencing high and low workload tasks
    f. Circadian factors – tasks in this population are those performed with crews that are off their normal circadian sleep cycles (i.e., a subset of scenarios run during night-shift)

g. Environmental factors such as poor lighting, high noise, radiological contamination, or other factors such as operator physical position. Tasks in this population are those that analysis identified as having environmental factors of interest in the hazards or other factors portion of the TA.

D.4.4 Sample Selection

HSIs and scenarios are selected from the representative population sample set that together fulfills the minimum conditions. [[

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The output of this process is a list of HSIs for verification and a list of scenarios for validation.

D.5 Human Factors Engineering Verification

The HFE verification activities are conducted to confirm that the design has been developed as intended. This means that the design fulfills the task requirements coming from the HFE TA (verified during TSV, Section D.5.4) and that the design is compliant with the HFE design requirements coming from the HFE DRD (verified during HFE Design Verification, Section D.5.5).

D.5.1 Human Factors Engineering Verification Inputs

The inputs for the HFE verification activities are the following:

1. HSI inventory and characterization – an inventory containing the HSIs and description of the HSI characteristics.
    a. This inventory is derived from each plant system UIS.

b. For each HSI, the following minimum set of information is included:

   i. Unique ID code

   ii. Plant system

   iii. Associated tasks (from TA)

   iv. Type of HSI (hardware/software, system/group, view/alarm, response procedure/ computerized procedure)

2. Task support inventory (alarms, controls, and indications needed to support tasks) – TA develops each task support inventory of HSIs in the context of a sequential process that shifts the system being manipulated from one system state to another.

3. Designed HSIs – the individual HSIs that have been verified by the HSI designers to individually meet task requirements, HFE design requirements, and regulatory requirements, and are implemented on the software and hardware platforms.

4. Control room, local field interface, and workstation layout specifications.

5. Task lists and task narratives from basic and detailed TA for TSV.

6. Results from link analysis and timeline analysis and workload analysis for TSV.

7. The HFE DRD (including the HSI style guide) for design verification – these provide a standard for implementation of HSI design requirements that ensure consistency across different aspects of the alarm, indication, and control systems.

The HFE COO provides support during the TSV for those operational aspects unassessed in the TA. The original standards and codes used to populate the HFE DRD are used to provide clarification for specific requirements during the design verification. Any HED identified during the HFE verification activities is documented and entered into HFEITS.

D.5.2 Human Factors Engineering Verification Scope

The scope of the HFE verification activities is the subset of HSIs that resulted from the sampling process described in Section D.4.

In the case that the same HSI displays are used at different facilities, they are verified in accordance with the applicable tasks performed at each facility because the task context, user access levels, and applicable procedures may differ from one location to another.

D.5.3 Human Factors Engineering Verification Tools

HFE verification performers use the following tools with the appropriate level of fidelity for the content and scope of each verification activity:

- Computer-generated displays – used to verify that HSIs required for the task being evaluated are present on HSI screens, and that the design, layout, and grouping align with HFE, regulatory, and HSI style guide requirements.

- Display emulators – static displays and drawings that are available first for verification allow the engineer to verify static features. Before broad scope simulation is available, emulator software provides the engineer with a means to verify the dynamic behaviors of the displays.

- Control room design drawings, 3D models, and mockups – control room design drawings are used to verify layout design requirements. 3D models and to-scale mockups are also used to verify layout design requirements, but also assist in verifying ergonomics, legibility, visibility, workstation design, and room layout before the simulator is available.
- High fidelity part-task and full-scope simulators –used to conduct verification activities, providing increasingly realistic system and plant response to user actions. Simulation is used to verify that the HSI designs correctly represent system and plant status and control response. Simulation is also used to verify task timing and sequencing.

D.5.4 Task Support Verification

TSV is the process that ensures that the HSIs and their characteristics meet operator task requirements as defined by the HFE TA process.

The objectives of TSV are to ensure that:

- The HSI inventory and characterization are consistent with the HFE analyses
- Each HSI component meets the requirements associated with a given task
- The overall HSIs provide alarms, information, and control capabilities required for operator tasks
- No unnecessary components, parameters, or alarms are present in the HSI design

TSV ensures that the HSIs provide the necessary components to support the tasks defined by the TA. Depending on the maturity of the plant procedures, the TSV provides the developers the opportunity to test procedures and portions of procedures during step-throughs.

D.5.4.1 Task Support Verification Acceptance Criteria

TSV compares the HSI elements (alarms, controls, and indications) identified during the detailed analysis of a task to the designed HSIs to ensure that components needed to complete the tasks safely and efficiently are present in the final design. The task support inventory and verification criteria are identified during TA. This provides the criteria against which the designed HSI are verified during TSV. This includes the following:

D.5.4.1.1 Task-Level Criteria

- Task prerequisites
- External initiating cues
- Task objective is available to be placed in service
- Start sequence information
- Actions taken
- Cues and information indicating the end of the task
- End state of the task was accomplished
- End state of the task achieved the desired results

- End state of the task is no longer needed and can be terminated

In addition to these criteria, TSV performers identify and verify in the HSI any other requirement from the task narrative:

- Personnel involved
- Time restrictions
- Aids and tools
- Communication needs
- Correct component labeling
- Location considerations

D.5.4.1.2 General HFE Design Principle Criteria

General HFE principles are established to guide the design of the HSI resources and their interrelationships and to serve as HSI TSV criteria. These principles are:

- Human-centered design – The primary objective of HSI resources is to support users. Aspects of the design basis of the HSI resources support the users in controlling, monitoring, and maintaining the plant.
- Minimize change to crew responsibilities – Thorough TA ensures that the responsibilities of each member of the operations and maintenance crew are well established. These responsibilities are defined in the context of the plant administrative protocols and technological limitations. By keeping the role of each operator and maintainer clearly delineated, undesired effects on procedures, communication protocols, and day-to-day activities are controlled.
- Technology simplification and optimization to improve user support – Technological advancements are a significant and primary driving force for HSI design. HSI technology and features are incorporated in a way that improves support to the user. Plant design ensures that full advantages of new technologies are realized.
- Uniformity of design – HSI resources appear in common forms throughout the design. This principle ensures that a user’s expectations for a resource are consistent and that they do not need to develop special knowledge for non-standard designs. As the system matures in its design life, there is a risk that exceptions can be a source of errors by systems and maintenance personnel that result in the degradation of the HSI performance. Uniformity in the equipment design ensures that the plant maintenance personnel can maintain familiarity with the equipment.

D.5.4.2 Task Support Verification Evaluation Methods

The HSIs and their characteristics (as defined in the HSI inventory and characterization) are compared to the personnel task requirements identified in the TA (and defined in the task support inventory and verification criteria). For each task, the requirements of the HSI are compared to the characteristics of that HSI.

D.5.4.2.1 Display Evaluation

For a system display, the TSV evaluation consists of the following steps:

1. Verify that the HSI correctly represents the system flow diagram. A system HSI displays look like a simplified version of a P&ID, with components and piping in the same or similar relative spatial relationships to one another.
2. Verify that supporting SSCs required for each task are in place, both active (e.g., valves, pumps) and passive components (e.g., filters, tanks). SSCs are provided as controllable, indication-only, or static as specified by TA.
3. Verify that component requirements (indications, messages, alarms, and controls) match with TA results (task support inventory and verification criteria):
    a. Labeling is consistent with TA, system P&ID, procedures, and follows project conventions.
    b. Indications are provided in the correct format; readout units, bar charts, and trends are provided as specified by the TA.
    c. Numeric readout units and number of significant digits correspond with task needs.
    d. Bar chart scale and tick marks are at the appropriate level of detail defined in the TA; include correct setpoint and alarm indications.
    e. Trends show the required parameters defined in the TA. Trend scale of axis and trend tick marks are at the appropriate level of detail defined in the TA.
    f. Alarms and cautions are consistently placed in accordance with task logical performance.
    g. Control capabilities are implemented in the components as defined in the TA. Control type and granularity is appropriate to the task (e.g., open/close, raise/lower, numerical entry).
    h. Key parameters [[ ]]$^{(a)(4)}$ are supported and emphasized as defined in the TA.
4. User aids identified in the TA (e.g., static graphs, calculation tools, data tables) are intuitive, transparent, and do not require interpretation, extrapolation, or generalization.
5. Taskbars, toolbars, menus, sub-menus, and navigation items (e.g., links to other displays) are appropriate to fulfill task needs. User access to needed displays and navigation is direct and efficient.
6. Access levels according to staff roles are properly implemented.
7. There are no unnecessary components, indications, controls, or static objects present in the HSI. Unnecessary components are those not required by any system task or with an unclear purpose.
8. Confirm that applicable results, HFE issues, and recommendations from HSI T&E, workload analysis, timeline analysis, and link analysis are incorporated in the HSI.

9. As the final confirmation, the performer can successfully complete tasks related to the system within the verified HSI.

The TSV evaluation of a different type of display, such as a group view display or a special purpose display, can add or omit specific steps due to the unique nature of these displays.

D.5.4.2.2 Procedure Step-Through

When the procedure development has matured, a step-through during the TSV is conducted. The main scope of the procedure step-through are the events that were developed during TA timeline and workload analysis. In addition, maintenance tests with specific procedures are verified with this activity.

At least one participant with a dual role of procedure reader and performer is needed for the step-through. Procedure step-throughs with more than one participant allow the V&V team to confirm that the number and roles of assigned staff is adequate to follow the procedure sequence. Step-through participants have an operations background and training/familiarity with the specific procedures.

This evaluation method is carried out following the procedure instead of a system-by-system TSV. Different HSIs are accessed by the performer as the step-through is conducted. The HFE V&V engineers make sure that the HSI satisfies the needs of each procedure step. This allows for cross-checking among procedures, HSI design, and TA. In this way, compatibility and consistency among task needs, HSIs, and procedures are ensured.

At the same time, the procedure is reviewed against the HSI and task needs obtaining valuable outputs for enhancement (e.g., missing steps, redundant steps, labeling inconsistencies, addition of cautions and notes, and findings regarding information levels).

D.5.4.2.3 Layout Evaluation

Evaluation of the control room and risk significant local field interface layouts is carried out during TSV in parallel with the procedure step-through using the same operation environment and procedures.

TSV layout evaluation is conducted on a 3D-mockup (physical or virtual). Some layout evaluations may also be conducted using drawings for simple tasks that do not need additional fidelity.

TSV layout evaluation focuses on the task requirements that involve aspects of the room space, such as location and positioning of workstations and VDUs, paths and movement patterns, communication and external devices, and operational aids. The layout evaluation uses the information from the timeline analysis and workload analysis collected during TA to assess and verify traffic workflows.

As a procedure is performed, the engineers verify that the task requirements for each step are in place and evaluate the actions done by the performers into the HSI environment in terms of time and workload criteria.

D.5.4.3 Task Support Verification Outputs

The primary outputs of the TSV process are groups of HSIs (including room layouts) that are verified to support the tasks they were designed to implement in accordance with HFE principles.

The outputs include deficiencies and unnecessary components identified and documented as HEDs. Documentation includes the HSI(s) involved, the associated tasks, and the basis and criteria for any identified deficiencies.

An HED is logged into the HFEITS if any of the following exist:

- Unsupported tasks – A required control, display, or alarm needed for task performance is not available.
- Partially supported tasks – HSI characteristics do not fully meet requirements (e.g., poor real-time response and feedback when using a manual/auto controller or inadequate pushbutton tactile feedback).
- HSI characteristics that do not match the personnel task requirements (e.g., a display shows the necessary plant parameter but not the range or precision needed for the task).
- Presence of unnecessary HSI components – They introduce clutter and distract personnel. An HSI component is considered unnecessary if it is not required for any personnel tasks.
- Any instances of found deficiencies or discrepancies in TA outputs.

Secondary outputs of the TSV are the improvements and recommendations to procedures in the case of a procedure step-through evaluation.

D.5.5 Human Factors Engineering Design Verification

HFE design verification evaluates the HSI designs using the criteria, requirements, and HSI style guide conventions contained in the HFE DRD. This verification ensures that the design complies with HFE design principles.

The objective of HFE design verification is to confirm that the HSI component design and environment conform to the HFE guidelines, standards, and principles reflected in the HFE DRD. While the TSV is focused on task requirements, the HFE design verification ensures compliance with requirements from various aspects:

- Static and dynamic HSI features:
    - Detailed (includes individual HSI features not addressed)
    - Standardized (display screen organization, display format conventions, coding)
    - Global (layout, workstation configuration, lighting, noise)
- Workstations and control room ergonomics
- Interface management features such as navigation and data retrieval
- Degraded HSI conditions
- Maintainability of digital systems

Conformance between as-built implemented design and the verified design is part of the design implementation and is conducted during the construction phase of the project on the as-built HSI.

D.5.5.1 Human Factors Engineering Design Verification Acceptance Criteria

The applicable criteria for HSI design are contained in the HFE DRD. HFE design verification criteria cover the following design aspects:

- Individual HSI elements meet application-specific (detailed) design requirements and criteria (e.g., individual component labeling and specific placement of an HSI element on an HSI display).
- HSI characteristics meet requirements for overall plant consistency across HSI platforms and implementations (e.g., consistent use of visual and auditory coding schemes, consistent user interaction schemes, HSI behaviors).
- HSI consistently incorporates HFE design requirements in displays containing plant-level, system-level, and other information. Integrated design features result in an intuitive process for maneuvering on and across screens for user tasks.
- Room layouts and hardware panel configurations meet HFE access, spacing, and layout requirements.
- NCR, RSF, local controls, and local field interfaces that support NI function areas meet environmental requirements (e.g., lighting, acoustics and auditory characteristics, temperature, and humidity).
- The HSI designs account for HF characteristics, capabilities, and coding stereotypes defined in the HFE COO (e.g., redundant coding to accommodate for color-blind users, ergonomic requirements for reach radius, viewing angles, line-of-sight, and foot and knee clearance).

D.5.5.2 Human Factors Engineering Design Verification Evaluation Methods

The designed HSIs and their characteristics (as defined in the HSI inventory and characterization) are verified against the HFE DRD.

Based on the HSI categorizations provided in the HSI inventory, each HSI feature (color, size, font, location) is compared to the applicable subset of HFE design requirements from the HFE DRD. Some HFE design requirements apply to multiple HSI elements. During HFE design verification, the HFE verifier documents each HSI element under evaluation (including document and page numbers, screenshots, or photographs), which subset of HFE DRD requirements were applied, and whether the HSI element passed or failed each requirement. For each failure (HED), the HFE verifier describes the non-compliance with sufficient detail (written descriptions supplemented with visual markups) to clearly communicate the specific problem or deficiency.

If the HFE verifier determines that specific additional features are not covered by the HFE DRD but must be, these are documented as an HED, with reference provided to the applicable criteria in the standards and codes that was found missing or deficient.

The following static and dynamic aspects of HSI components and characteristics are included in the verification against the HFE DRD:

- Information display
- User interface interaction and management

- Analog display and control devices
- Workstation and workplace design

Standardized HSI elements within the configuration-controlled HSI element library may have standard (non-display specific) characteristics (e.g., size, color, shape) verified once, at the level of the library, rather than at every individual application on a display.

Installed groups of HSIs, panels, and the control room layout and environment are compared to design requirements from the HFE DRD to verify that the design is correct.

Ergonomic evaluation is performed to check that the design complies with the HFE DRD. Ergonomic evaluation is verified using 3D models or mockups against the defined user population limitations, capabilities, and anthropometric data in the HFE COO. This includes:

- Reach and accessibility of control devices (control positioning and grouping)
- Legibility and visibility of indications (viewing distances and angles)
- Seating comfort – The relationship of working surface height and area, knee room, chair height, and seat adjustability

Evaluation of environmental aspects (e.g., lighting, noise, temperature, ventilation) is first accomplished by comparing HFE DRD requirements to mechanical (heat, air, ventilation, and cooling) and electrical (lighting) specification documents to verify that the specified values comply to the HFE requirement values. Additional verification may be performed on the global attributes of the full-scope simulator (such as control room acoustics and glare)), if available with sufficient fidelity . Note that some of these aspects are not closed until construction, so the verification of the related guidelines remains pending. These unaddressed aspects take part during the design implementation element.

D.5.5.3 Human Factors Engineering Design Verification Outputs

The primary output of the HFE design verification process is the HSIs (including room layouts) that have been verified to properly implement the design in accordance with HFE principles and regulations.

Additional outputs include any instances of non-compliance, full or partial, from accepted HFE guidelines documented as HEDs. HEDs involving standardized features are evaluated further to identify potential discrepancies across HSIs with similarities in the standardized characteristics. For example, identifying an inappropriate format for presenting data on an individual display could indicate that other display formats may be incorrectly used, or that the observed format is inappropriately used elsewhere.

The following HEDs are logged into the HFEITS:

- Any instances of non-compliance with design requirements from the HFE DRD
- Any instances of found deficiencies or discrepancies in HFE DRD requirements

D.6 Human Factors Engineering Validation

HFE validation, which includes ISV, is the performance-based evaluation of the integrated HSI design. Simulations are used to validate the ability of operators to use the integrated HSI to support safe plant operations. The validation is intended to evaluate those integrated aspects that were verified one by one through analytical means (e.g., TSV or HFE design verification activities). ISV is performed using high fidelity simulators.

The ISV is the final activity that ensures the integrated design is fulfilling its intended function. The integration of HSI elements is achieved by using simulators. The simulators include software HSIs mounted into the panels and workstations, replicating control room layout design, and simulating environment conditions.

HF ISV evaluates the performance of the integrated HSI design in terms of plant metrics, personnel tasks, crew communications and coordination, situation awareness, workload, anthropometric, and physiological factors. HF ISV scope includes validation of:

- The role of plant personnel.
- Adequacy of procedures.
- Acceptable shift staffing, assignment of tasks to crew members, and crew coordination (both within the control room as well as among the control room and local field interfaces and support centers). This includes validation of nominal shift levels, minimal shift levels, and shift turnover.
- Automation functions (AOFs and the degree of task dependence on procedures).
- Adequacy of the integrated HSI configuration for achieving HFE program goals consistent with HFE guidelines, principles, and methods.
- Adequacy of the HSI to support the crew in accomplishing critical functions and tasks. For each task, the design provides adequate alerting, information, control, and feedback capability for human functions performed under normal plant evolutions, transients, design-bases accidents, and selected, risk significant events that are beyond-design basis.
- The effect of HSI characteristics on operator workload.
- The crew’s ability to make effective transitions between the HSIs and procedures while conducting tasks. Interface management tasks such as display configuration and navigation are not a distraction or undue burden.
- HSI facilitation of efficient search and retrieval of information and controls.
- Accomplishment of specific personnel tasks within time and performance criteria, with a high degree of operating crew situation awareness, and with acceptable workload levels that provide a balance between a minimum level of vigilance and operator burden.
- HSI minimization of operator error and provision for error detection and recovery capability when errors occur.
- Integrated system tolerance of human error, system faults, and failures of individual HSI features.
- HAs categorized as risk-important in the PRA and HAs credited in the safety analysis for mitigating events.

In addition to these, the ISV identifies any additional aspect that may negatively affect human performance. Discrepancies identified during previous verification activities are corrected prior to ISV to prevent unwanted effects on the integrated validation results.

D.6.1 Human Factors Engineering Validation Inputs

Input from the following is taken to implement and develop the validations:

- Set of scenarios for validation - The operational condition sampling provides a list of scenarios that maximize relevance and significance while ensuring diversity of conditions.
- TA - Task narratives help the ISV observers to understand and identify [[ ]]$^{(a)(4)}$, tasks that are a potential source of error, sequences of tasks that imply high workload situations, and communication tools and operation aids used by the operators during the validation.
- Timeline, link, and workload analyses - Performed for task performance optimization, providing the HFE observers information for performance measures analyses during the ISV.
- HSI T&E Results - The inform the ISV about considerations from prior testing to test design. Issues and recommendations from HSI tests and evaluations are already incorporated in advance of the ISV and early validation.
- Staffing Analysis - The staffing analysis provides the ISV observers with the roles and responsibilities of the operators during the tests and focal points of the scenario when additional personnel are needed.
- HSI Inventory and Characterization - The inventory of HSIs and HSI characteristics is used as input when developing validation testbeds. The inventory is also used to verify that the HSIs in validation testbeds are complete and have the appropriate fidelity for the scope of the integrated system test being performed.
- HSI Layout Design - Layout drawings are used by the V&V team to previsualize movements during operation and to find a proper location for the observer to follow the operator’s actions without interrupting them.
- Procedures - Procedures define how a crew must respond to the conditions and events presented during integrated validation testing scenarios. The ability of the crew to select and successfully carry out the correct procedures within the integrated system plays an integral role in the validation of that system.
- Training - Training provides an input to integrated validation by determining the level of knowledge and skills that the operating crews possess during validation testing.
- COO - Conduct of operations provides an input to integrated validation by defining the standards for the execution of operational and management tasks. This includes defining the way test participants are expected to respond to alarms, use operating procedures, interact with one another on shift (e.g., peer checks, communications, briefs, and shift turnover), perform shift rounds, and maintain shift records and log keeping.
- HFEITS - Issues/HED resolutions are implemented in the appropriate HFE design process. Final issues/HED resolutions are validated within the scope of the integrated system and provide input to testing in addition to specified tasks and conditions.

D.6.2 Human Factors Engineering Validation Scope

The scope of the ISV and early validations is the list of scenarios selected after the sampling of operational conditions process. [[

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As described in IEEE 2411-2021 (Reference 16), using a multiphase approach to HFE validation is a concept that has been developed in the last few years within the HFE field and is considered good practice. Early validations, multi-stage validation, phased validations, preliminary validations, and partial validation are different names given for this same concept.

Following the latest state-of-art methodologies, the project uses a multiphase validation. In this way, the V&V team receives early feedback from potential end users and the design is refined during the iterative HFE activities.

According to NEA No. 7466 (Reference 21), there are three main characteristics for a multiphase approach:

1. The multiphase validation is conducted as a series of validation activities, each with its own objective(s), method(s), and result(s).
2. Each validation activity included is designed to provide information that is used as part of the basis for determining whether a system can accomplish its intended use, goals, and objectives in a specified environment.
3. Individual validation activities are conducted and grouped in time as stages that allow meaningful aggregation, summation, or comparison of results, both within and across stages, to support interim or final validation conclusions.

Validation efforts start from conceptual design phases and continue throughout the licensing and detailed design phases. During project life, several validations are expected without all of them having the full characteristics of an ISV.

Those are early validations and they do not have the same primary intent as ISV. Early validations are performed to identify and solve HFE issues in advance improving HFE cycle and design process efficiency. They require a sufficient maturity of the design, HFE participants from the V&V team, and end users with enough level of familiarity with the system.

The results from each early validation contribute to accumulated evidence for validation of the integrated design. There are several reasons to perform early validations, for example:

- One RO workstation replica is ready with system displays integrated (part-task simulator), but the complete simulation of the control room environment is not ready.
- A set of procedures is ready but not all procedures that fully cover the sample list of scenarios have been prepared.
- A project milestone is approaching, and the robustness and maturity of the design is probed.
- A specific maintenance test is validated separately.
- Specific improvements in the design due to HEDs and HFE issues have been implemented and must be revalidated.

This plan specifies the objectives, methods, and outputs of the ISV. The early validations comprehensively follow the same guidance. However, they are not required to strictly perform all methods described here.

Figure D.6-1 depicts the concept of multiphase tests and validation.

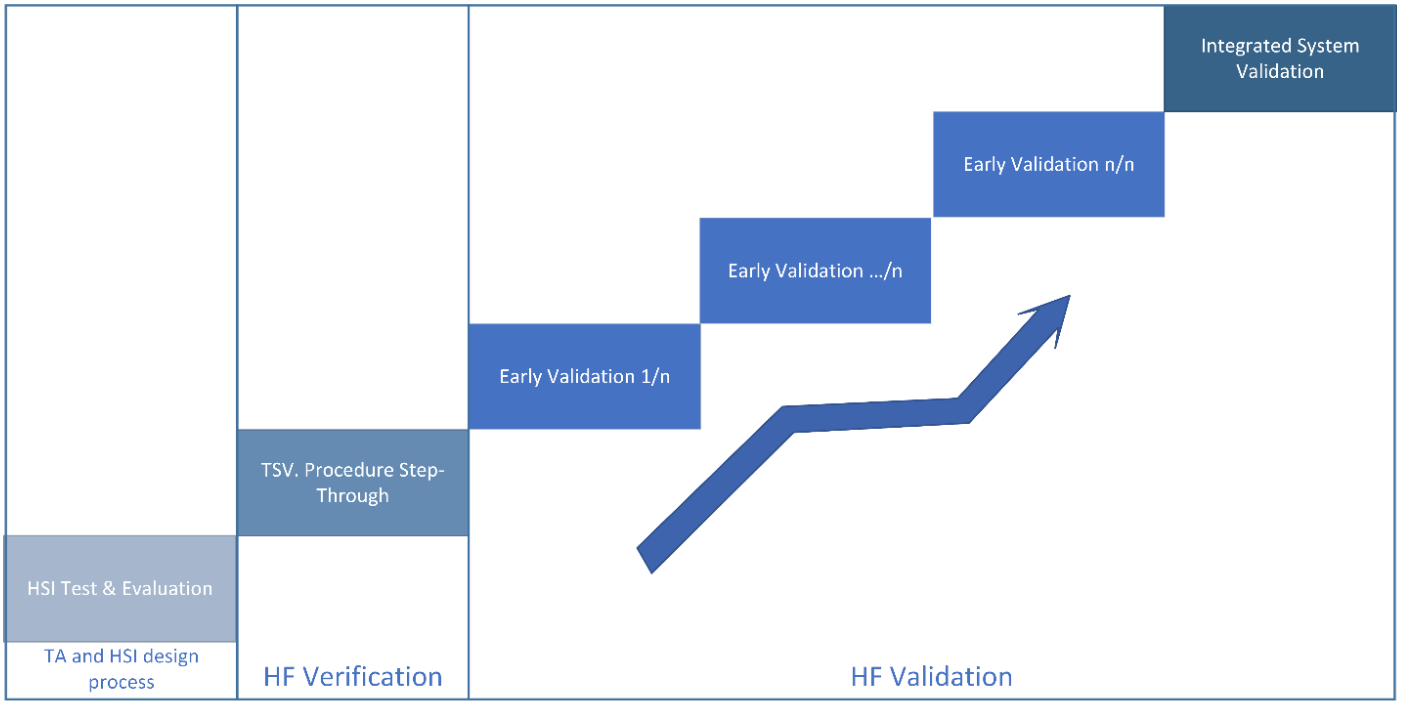

Figure D.6-1: Multiphase Testing and Validation Approach

Figure D.6-1 includes the preliminary HSI testing activities and TSV procedure step-through, as they are tests that share fundamentals and types of checks with the validation trials. However, HSI T&E is not considered a V&V activity, as the design is not yet mature and the participants (observers and executors) are not required to meet independency criterion and perform extended training.

D.6.3 Human Factors Engineering Validation Tools

D.6.3.1 Human Factors Engineering Validation Simulator Testbeds

D.6.3.1.1 Types of Simulators

The simulators used during HFE validation activities are described in this section. Use of the simulators by HFE is coordinated with the training department and the simulator group.

In alignment with the multiphase testing and validation approach described in IEEE 2411-2021 (Reference 16), the level of development and fidelity of the simulator and testbed are proportionate to the phase of testing in which they are being used and the HFE design features that are being validated.

During design phase, a simulation engine provides a representation of the operation and responses of the plant. A generic plant simulation model is used by the HFE team on a computer workstation-based platform or glass-top based platform for HSI development and HFE tests and evaluations. As site-specific system models become available, tests are conducted using the site-specific models instead, using generic or simplified models of the remainder of the plant systems. These intermediate phases are referred to as a part-task simulator.

The part-task simulator is run on computer-based workstations containing VDUs and input devices (i.e., mouse and keyboard) to demonstrate display and panel design and functionality. The computer workstation-based simulation platform is used by the HFE team for the development and testing of HSI display and panel designs, and the initial development and testing of the plant normal, abnormal, and emergency operating procedures.

The part-task simulator includes basic functions, such as establishing desired initial conditions, triggering events, backtracking, and real-time/historical trending.

During earlier phase testing, the hardware for the part-task simulator consists of enough table/desk space and VDUs to simulate one console section of the control room design and the required input devices and computers. During later phases of testing, additional workstation space is added to accommodate multiple users.

To increase platform fidelity, the computer workstation-based simulation platform is integrated into a mock-up. Mock-ups may use a glass-top simulation platform implemented with programmable displays and touch screens, which are configured to represent hardware-based panels, having the hardware-based controls and indications active so that the user can use the hardware-based controls and observe the hardware-based indications. Integration of the computer workstation-based simulation platform into the mock-up allows the HFE team to conduct more complete walk-through HSI assessments, as this configuration provides the hardware and software-based controls and indications needed to perform user tasks.

Additional fidelity is added when the full-scope simulator becomes available, which contains the simulation models for plant systems included in the detailed system design, and can perform normal, abnormal, and emergency plant operations.

The hardware for the full-scope simulator consists of a full-scale mockup of the control room.

D.6.3.1.2 Validation Testbed Requirements

As described in IEEE 2411-2021 (Reference 16), a simulator must meet the fidelity requirements for the systems and HFE design features being tested within the scope of that test scenario, as defined within the test plan for that phase of validation testing.

The following testbed fidelity requirements are met for the scope of the validation activity being conducted:

- Interface completeness – The testbed completely represents the system being tested, including HSIs and procedures.
- Interface physical fidelity – The testbed represents a high degree of physical fidelity in the HSIs and procedures. This includes the presentation of alarms, displays, controls, job aids, procedures, communications, interface management tools, layout, and spatial relationships.
- Interface functional fidelity – The testbed represents a high degree of functional fidelity in the HSIs and procedures. HSI functions are available within the system being tested, including HSI component modes of operation.

- Environment fidelity – The testbed represents a high degree of environment fidelity. The lighting, noise, temperature, and humidity characteristics reflect the expected plant environment to the extent practicable.
- Data completeness fidelity – The information and data provided to test participants completely represents the plant systems monitored and controlled from that facility.
- Data content fidelity – The testbed represents a high degree of data content fidelity. The information presented during the scenario accurately depicts information that is presented in the plant.
- Data dynamics fidelity – The testbed represents a high degree of data dynamics fidelity. The process model provides input to the HSI in a manner such that information flow and control responses occur accurately and in a correct response time (e.g., information is provided to personnel with the same delays occurs in the plant).

D.6.3.1.3 Testbed Verification

To ensure that fidelity requirements are met, the testbeds are verified as matching the plant at each phase of validation testing by noting that the same software and computers used for development of the part-task simulator and full-scope simulator match what is to be installed the plant. Testbed verification is accomplished during pilot tests conducted prior to validation.

To make sure testbeds accurately reflect the current design, the HSI is adjusted as the system is developed so that by the time the full-scope simulator is developed, the HSI design is stabilized. The software system for simulating plant behavior is upgraded as improved data becomes available for the plant sensors, controllers, and other components.

The scenario validation process verifies that cues, indications, communications, and feedback built into the event guide are accurate and timely. In this way, scenarios containing actions that occur outside of the control room are accurately rendered and support validation of the integrated system HSI.

The risk significant local field interfaces and their HSIs are verified in accordance with the TSV and HFE design verification processes. Additionally, ISVs that require actions to be performed at local field interfaces are performed using action durations, simulated feedback indications in the HSI, and communication mechanisms used in the plant. Scenarios model local tasks important to scenario timing and fidelity as well as the local tasks important to risk or safety.

Validation of risk significant local control operations is performed using simulations and mockups. Factors associated with local operations incorporated into a scenario are specified, in detail, in the event guide written to govern performance of the simulation. The scenario validation process verifies that remote manual action cues, indications, communications, and feedback built into the event guide are accurate and timely. Thus, scenarios that contain remote actions are accurately rendered and support validation of the integrated system HSI.

D.6.3.2 Human Factors Engineering Validation Data Collection Tools

During HFE validation testing, the following types of tools support data collection:

- Data collection forms
- Observation tools

- Event questionnaires
- Interviews and debriefings

Use of these tools is discussed within each of the relevant sections, as shown in Table D.6-1.

Table D.6-1: Summary of Integrated System Validation Data Collection Forms and Observation Tools

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Table D.6-1: Summary of Integrated System Validation Data Collection Forms and Observation Tools

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D.6.4 Human Factors Engineering Validation Scenario Set Identification and Development

ISV scenarios that exercise the selected operational conditions are developed using a structured process to ensure consistency, quality, confidentiality, and the minimization of bias. This includes coordination with the operations training department and training schedule to ensure that HFE ISV testing scenario content and schedule do not overlap with training contents and schedule (e.g., training of an uncomplicated loss of off-site power event immediately followed by an ISV scenario testing the same thing). Procedures governing the performance of the ISV process contain guidance regarding the requirements for development and documentation of scenario attributes, including:

- Objectives
- Initial conditions
- Selecting and documenting events
- Scenario attributes, both qualitative and quantitative
- Determining scenario endpoint

- Validation of the scenario itself
- [[ ]]$^{(a)(4)}$

D.6.4.1 Identifying Scenario Objectives

Scenarios are assigned a predetermined set of specific objectives based upon the events that take place during the scenario and the attributes, abilities, procedures, and training to be validated. The basic objective of the scenarios is to evaluate the operators' ability to effectively use the HSI to respond to the event being simulated. Specifically, each scenario validates the attributes of the associated HSIs and procedures, and the operators' training experiences with them, through observations of the operators' knowledge of and the ability to:

- Conduct integrated plant operations (gained through training)
- Use the integrated HSI to gather and validate indication and plant performance data
- Diagnose abnormal plant conditions
- Formulate mitigation strategies
- Locate and use the appropriate procedures
- Use the integrated HSI to implement the chosen mitigation actions
- Communicate effectively within and outside of the control room environment

Additionally, each scenario contains objectives specific to the operational conditions and events that are contained in it, including validation of the ability to meet:

- Event and scenario acceptance criteria
- Supplemental event and scenario criteria

D.6.4.2 Initial Conditions

Scenarios are assigned a predetermined set of initial conditions established to allow the simulated scenario to commence realistically. The initial conditions are representative of typical plant status at the time in the plant operating cycle in which the scenario is to take place. Additional initial conditions are included for realism and may include tagged out components or systems, in-progress maintenance, or testing. To eliminate predictability, some initial conditions that have no bearing on subsequent scenario events are included. Specific initial conditions that are covered in the scenario shift turnover are identified.

D.6.4.3 Selecting and Documenting Events

After initial conditions are established, a sequence of events is developed to achieve the scenario objectives. Each event either directly supports or contributes to the support of one or more objectives. Scenarios are developed so that various systems are affected by each type of event, such as:

- Degradation or failure of instruments, controls, and components
- Major plant transients and accidents
- Normal plant maneuvering

Realistic conditions limit the predictability, recognizability, and potential bias from operator expectations of scenario event timelines. Some scenarios incorporate equipment failures that cause or exacerbate problems in other systems. This practice allows validation of the HSI design and its ability to support understanding of system and component interactions, integrated system operations, and the integrated HSI performance across a broad range of conditions.

Scenarios are not a series of totally unrelated events. ISV scenarios are designed to flow from event to event, giving operators sufficient time to:

- Analyze what has happened
- Evaluate consequences of action options
- Evaluate consequences of inaction
- Assign priorities to the event based upon current plant conditions
- Determine a course of action
- Implement the actions
- Observe and evaluate response of the plant

Scenario designers pre-determine each planned operation, malfunction, and transient and document them as a scenario timeline. Scenario documentation includes:

- Event descriptions
- How and when the event is initiated
- A listing of the event cues, indications, and symptoms that is available to operators
- Expected actions to take
- Expected communications
- Procedures to use
- Scenario endpoint
- Required operator actions to observe, including [[ ]]$^{(a)(4)}$ contained within the scenario
- Expected task times for required actions, [[ ]]$^{(a)(4)}$
- Other variable actions and behaviors that provide useful basis for evaluating operator and integrated HSI performance

D.6.4.4 Qualitative and Quantitative Scenario Attributes

ISV scenarios are constructed to accurately test:

- Integrated HSIs support each individual operator's abilities and skills
- Integrated HSIs support crew member's team-dependent abilities and skills
- Integrated HSIs support safe and efficient operation
- Procedures
- Training
- Staffing and qualification criteria

Each scenario is of sufficient length, scope, and complexity to allow differentiation between acceptable and unacceptable performance. Scenario attributes consist of both qualitative and quantitative elements. Experienced scenario developers use scenario attributes to both construct and assess the quality of the scenarios. This assessment, combined with scenario validation, ensures the scenario is an acceptable tool to validate the integrated HSI and crew operating it. The following are attributes used to develop and assess scenario acceptability:

<u>Scenario Qualitative Attributes</u>

- Realism/credibility (plant and personnel responses)
- Event sequencing
- Simulator modeling
- Evaluating competencies
- Level of difficulty

<u>Scenario Quantitative Attributes</u>

- Normal evolutions
- Number and sequence of malfunctions
- Abnormal events and major transients
- EOPs and contingencies used
- Total run time
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Table D.6-2: Determining the Level of Scenario Complexity

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D.6.4.5 Determining Scenario Endpoint

A scenario endpoint is selected and documented. The endpoint specified identifies a particular plant condition, procedural step, plant parameter, or other clearly recognizable condition. The endpoint parameter is specifically selected allowing completion of scenario objectives prior to scenario termination.

D.6.4.6 Validation of the Scenario (Pilot Testing)

The structure, timeline, flow, and other aspects of ISV scenarios are validated prior to use. Scenario validation ensures that the scenario runs as intended and that supporting scenario development and execution materials are accurate.

D.6.4.7 Task Determination

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D.6.4.8 Measures Taken to Eliminate or Control Scenario Development Bias

Bias represents any influence, condition, or set of conditions that singly or together distort the data. Bias can produce systematic (but unexpected) variation in a research finding and can invalidate any conclusions made based on a biased sample. When selecting operational conditions and developing scenarios, care is taken to avoid creating a biased sample.

Qualified test personnel control scenario bias through several means. These include:

- Procedurally controlled scenario development and validation process
- Ensuring validation tests are performed using scenarios that cover a representative range of conditions by selecting from the full range of operational conditions
- Scenario validation, which includes an evaluation of scenario attributes and their distribution
- Pilot studies identifying possible sources for scenario bias and for developing controls
- Backcasting – This is part of the scenario ID and development process that involves identifying a future state (both desirable and undesirable) as identified in SAMGs, EOPs, AOPs, alarm response procedures, and normal operating conditions. It involves constructing paths that connect the specified end condition to the conditions and actions required to achieve or avoid it.

This approach reduces the risks of hidden bias in construction of scenarios. By selecting both desirable and undesirable outcomes, and by developing scenarios with conditions and events that vary the likelihood of reaching the outcome, a representative and balanced set of scenarios is identified.

D.6.4.9 Scenario Set Review and Approval

After scenario development is complete, the resulting set of scenarios is evaluated and approved by the HFE V&V technical lead. Scenarios are also evaluated by the training team to ensure scenario event guide compatibility with procedures.

HFE scenario evaluation includes ID of selection bias in any of the following areas:

- Scenarios for which only positive outcomes are expected – [[

  ]]$^{(a)(4)}$ This type of bias is also avoided by following the backcasting methodology.

- Scenarios that are relatively easy to conduct administratively (scenarios that place high demands, data collection, or analysis are avoided) – Scenarios are developed that best accommodate the selected tasks and conditions and not just those scenarios that are the easiest to conduct.
- Scenarios that are familiar and well structured (e.g., those which address familiar systems and failure modes that are highly compatible with plant procedures such as textbook design basis accidents) – Because scenarios are developed from selected operational conditions, and because event sequencing is built in as part of scenario definition, it is not expected that scenarios follow highly familiar sequences.

If development bias is detected, scenarios are analyzed for alternatives to create a more fair and representative range of events. Any occurrences of significant sampling bias are logged as HEDs in the HFEITS for tracking and resolution.

D.6.5 Scenario Detailed Definition and Documentation

The ISV scenarios selected during the operational conditions sampling and scenario development process are defined so that they can be performed on a simulator. Scenario definition is used to provide a consistent, objective, and high-fidelity environment to validate performance of the integrated systems. The defined scenarios involve major plant evolutions or transients, reinforce team concepts, and identify the role each individual plays within the team.

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D.6.5.1 Cover Sheet

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D.6.5.2 Administrative Information Sheet

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D.6.5.3 Console Operator Instructions

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D.6.5.4 Event Guide

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D.6.5.5 Communication Scripts

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D.6.5.6 Task Summary

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D.6.5.7 Safety Analysis and Probabilistic Risk Assessment Acceptance Criteria

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D.6.5.8 Shift Briefing Information/Transfer of Authority

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D.6.5.9 Termination Criteria

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D.6.5.10 Questionnaires

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D.6.5.11 Event and Task Fidelity

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D.6.5.12 Realistic Simulation of Remote Responses

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D.6.5.13 Staffing Objectives

One goal of ISV is to validate the staffing levels established in the HFE COO and refined during the staffing analysis process. Staffing for the performance of ISV testing scenarios uses crew members enrolled in the initial licensed operator training program or licensed individuals. Crews are selected to ensure a mix of both experienced and new operators are evaluated within a crew and provide input regarding the HSI. Crew composition is set for each scenario during the ISV. Existing operations crews may be used, provided crew composition meets the balance of experienced and less experienced team members required for HFE ISV. Test participants are not allowed to act as a crew member in any scenario more than once. Sequestration principles and testing agreements are created and maintained prior to and during the ISV.

Scenario events and tasks that result in common issues for test participants are documented as HEDs in HFEITS to track the HFE or HSI factors that that require modification to resolve the issue. Tasks that result in the failure of the plant or crew to meet established acceptance criteria are added as HEDs and tracked to resolution in HFEITS.

D.6.6 Human Factors Engineering Validation Participant Selection

The participant selection pool for early validation activities using the part-task simulator may include trainers, licensed SROs, licensed operators from other plants, startup engineers, I&C engineers, PRA engineers, procedure writers, and HF engineers. The crews used during the later ISV activities can include individuals enrolled in the initial licensed operator training. The sample of participants used in testing reflects the characteristics of the population from which the sample is drawn.

D.6.6.1 Participant Sampling Criteria

The variables contributing to task performance variation are identified and considered during sampling to ensure that variation along those dimensions is included in ISV. These population characteristics are defined in the HFE COO and include:

- License, qualifications, and shift staffing – Crew size reflects the minimum staffing detailed in the HFE COO. There are at least two SROs and two operators in each crew.
- Skills and experience – A range of skills and plant OE is included to represent the depth and diversity of job duties and experience to approximate the range typically found in operational personnel.
- Minimum operations staffing

During full-scope simulator HSI testing, a minimum of three crews are tested, using the minimum crew staffing configurations defined in the HFE COO.

D.6.6.2 Prevention of Participant Sampling Bias

Randomized sampling is used to select participants from a population representative of the plant personnel who interact with the HSI. To prevent sampling bias, the following personnel are ineligible for participation:

- Participants who are part of the design organization
- Participants who were involved in prior design evaluations (however, participants may perform a training evaluation following the initial licensed operator training program)
- Participants who were selected for some specific characteristic (selecting only good or experienced crews)

D.6.7 Human Factors Engineering Validation Performance Measures

A hierarchal set of performance measures is selected to assess the adequacy of the integrated system. The plant/system performance measures selected for integrated validation are selected based on the prevention or mitigation of transients and accidents. [[ ]]$^{(a)(4)}$ Two types of performance measures are defined for the ISV:

1. Decisive measures – Decisive measures are used to pass or fail the validation test for the scenario under investigation, thus confirming that the integrated elements of the design are effective in achieving the goals of the scenario. [[

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2. Supplemental measures – Supplemental measures are collected providing additional information in support of validation efforts and to refine/enhance the design. Supplemental performance measures provide additional information regarding the results of other performance measures. Significant problems in these areas are also evaluated and addressed. Potential performance concerns identified in supplemental measurement areas are evaluated in the context of overall scenario performance and HEDs are written if needed.

Supplemental measures include:

   a. Crew communication and coordination
   b. Situation awareness
   c. Workload (both physical and cognitive)
   d. Ergonomics and physiological factors

Satisfactory completion of ISV and associated performance measures and criteria validates the HSI and the context where it is used. This includes automation, training, procedures, and staffing and qualifications.

D.6.7.1 Plant – Core Thermal-Hydraulic Condition

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D.6.7.2 Plant –Safety Analysis and Probabilistic Risk Assessment

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D.6.7.3 Personnel Tasks

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D.6.7.4 Crew Communication and Coordination

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D.6.7.5 Situation Awareness

Situation awareness involves being aware of what is happening in the plant to understand how information, events, and operator actions affect the goals and objectives, both now and in the future.

As discussed in "Measurement of Situation Awareness in Dynamic Systems" (Reference 22) and NUREG/CR-6393 (Reference 17), an objective measure of situation awareness is obtained by directly comparing a performer's reported situation awareness to reality. To achieve this objective, after a testing session, operators' perceptions about a situation are compared to the reality of the situation (as determined by information recorded on the simulation computers). Comparing the data in this manner provides an objective, unbiased assessment of situation awareness.

During early validation testing, the human-in-the-loop simulation is frozen at randomly selected times and the system displays are blanked while the operators quickly answer questions about their current understanding of the situation.

However, because freezes throughout a scenario interrupt the flow of the scenario event (making the scenario less representative of a real event) and because freezes may potentially degrade participant performance, by interfering with the efficacy of other performance measures, during the ISV pilot and the ISV scenario freezing is not used to measure situation awareness. Instead, during ISV, questions to measure situation awareness are administered immediately following completion of a scenario. Assessment of situation awareness during ISV pilot testing and ISV is supplemented through observer, video, and instructor station recordings of participant task performance and participant debriefing and self-reflection of performance outcomes. Additional supplemental information is provided by using participant eye-movement tracking, as gaze direction tends to strongly correlate with attention and cognitive activity.

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During testing, crews attend to tasks as during other simulations, with situation awareness queries being considered secondary. No displays or visual aids are visible while participants are answering questions (therefore screens are blank during testing, or test participants are asked to turn away from screens). If participants do not know or are uncertain about the answer to a question, they are encouraged to make their best guess. If participants are not comfortable enough to make a guess, they are permitted to skip that question and go to the next question. Talking or sharing of information among participants is not permitted. All participants are queried at the same time.

During a test, all screens go blank except for one screen in a central location at each workstation. On this screen, a series of situation awareness questions are presented, and the operators type/select their responses. Although this is the preferred method of administering the Situation Awareness Global Assessment Technique probe, another laptop computer, tablet, or paper version of the questions is acceptable.

Questions are relevant to the information that is available to operators prior to point of test administration. Questions are constructed in terms of operating procedures and phrased using language standard to the nuclear industry.

Questions cover three different levels of situation awareness: (a) perception of data; (b) comprehension of meaning; and (c) projection of the future. Questions include how the system is functioning and system status.

Situation awareness questions reflect requirements developed based on information provided by TA, training, and operating procedures. These requirements indicate what information an operator needs an awareness of to successfully complete the required tasks in a scenario.

The participant’s situation awareness, as determined by answers to the situation awareness measurement questions, are compared to situation information recorded on the simulation computers just prior to, and at the same point in time as, the freeze or point of test administration.

Situation awareness is measured in terms of:

1. Perception of data
    a. The proportion of correct answers relative to the total amount of data requested by the questions for each scenario
    b. The proportion of unanswered data questions relative to the total number of data questions
    c. The proportion of incorrect answers relative to the total number of data questions
2. Comprehension of meaning
    a. Awareness is adequate to correctly comprehend the meaning of the data attended to (Yes/No)
    b. Accurate or inaccurate judgment of plant/plant system status
    c. Accurate or inaccurate selection of procedure in response to data
3. Projection of the future
    a. Awareness is adequate to correctly predict events occurring in the plant in the future, based on data attended to and conclusions drawn from that data (Yes/No)
    b. Accurate or inaccurate selection of procedure in response to data
    c. Accurate or inaccurate prediction of plant/plant system status

Perceived operator information is compared to the information requirements needed to select the appropriate procedures to follow and to successfully complete required tasks, as determined by the TA and operating procedures.

Acceptability of performance is determined by assessing the level of situation awareness in the following way:

- Perception of data – The operators can provide a minimum of half the data requested. If the crew does not submit responses for over half the data points requested, an HED is entered into the HFEITS.
- Comprehension of meaning and projection of the future – The operators' answers accurately reflect the current situation awareness of the plant, based on the information available.

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D.6.7.6 Workload

Workload represents the cost incurred by a performer to achieve a particular level of performance. Workload is divided into two elements: physical workload and cognitive workload.

D.6.7.6.1 Physical Workload

To evaluate physical workload effect on performance, video recordings and observations by test personnel are used to identify conditions that represent any of the following (number of occurrences per day are predicted using the sample of occurrences during the time frame of a scenario):

1. Forceful exertions (e.g., carrying or lifting heavy loads)
    a. Heavy, frequent, or awkward lifting
        i. Any lift of 75 pounds or more
        ii. Lifting 55 pounds or more ten times per day
        iii. Lifting 10 pounds or more two times per minute over two hours total per day
        iv. Lifting 25 pounds or more 25 times per day and lift is above the shoulders, below the knees, or at arm's length

   b. High hand force
      i. Task results in any of the following for more than two hours per day: pinching an unsupported object weighing two or more pounds per hand, or pinching with force of four or more pounds per hand
      ii. Gripping an unsupported object weighing ten or more pounds per hand, or gripping with a force of ten pounds or more per hand
   c. Repeated impact
      i. Using the hands or knees as a hammer more than ten times per hour for more than two hours total per day
2. Posture
   a. Awkward postures (e.g., bending, twisting) – tasks that result in any of the following postures for more than two hours per day
      i. Working with the hand(s) above the head or the elbow(s) above the shoulder(s)
      ii. Repetitively raising the hand(s) above the head or the elbow(s) above the shoulder(s) more than once per minute
      iii. Working with the neck bent more than 45º (without support or the ability to vary posture)
      iv. Working with the back bent forward more than 30º (without support or the ability to vary posture)
      v. Squatting or kneeling
   b. Static postures
      i. Maintaining fixed positions for a long period of time (over 30 minutes) without breaks
3. Repetitiveness
   a. Highly repetitive motions (e.g., frequent reaching, lifting, carrying)
      i. Using the same motion with little or no variation every few seconds (excluding keying activities) for more than two hours total per day
      ii. Intensive keying or use of mouse for more than four hours total per day
4. Vibration
   a. High hand or whole body vibration
      i. Using hand tools that typically have high vibration levels more than 30 minutes total per day
      ii. Using hand tools that typically have moderate vibration levels more than two hours total per day

5. Pressure points
    a. Grasping, or contact from, loads, leaning against parts or surfaces that are hard or have sharp edges

Test personnel document the type, frequency, and context of high physical workload occurrences. To determine weight, vibration, and other environmental characteristics that affect workload, measurements may be taken by test personnel before or after a scenario. Measurements are conducted in a manner that does not interfere with simulator testing activities.

Ergonomics rules are based on the State of Washington Department of Labor and Industries, “Evaluation Tools” (Reference 23) and the NIOSH guideline, “Ergonomics Guidelines for Manual Material Handling” (Reference 24). These references provide the basis for determining acceptable workload. Any observations of physical workload occurrences that exceed the criteria are documented as HEDs in the HFEITS.

D.6.7.6.2 Cognitive Workload

Mental or cognitive workload refers to the information processing resources required of an operator in achieving task goals. Because excessive cognitive workload is associated with decreased situation awareness and decreased ability to perform safety significant tasks, knowledge of an operator’s mental workload is required to ensure that it is within acceptable limits. Because of the relationship between cognitive workload and situation awareness, both measures are evaluated in the context of one another.

TA is an important component of workload measurement. TA is used to determine the [[ ]]$^{(a)(4)}$ workload assessment. As such, the results of the operational analysis, including TA, is used as a screening mechanism by which tasks, scenarios, and situations are meaningfully selected for cognitive workload assessment. [[

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For the HFE V&V, tasks and event sequences are chosen for development of ISV scenarios representing high and low workload that preliminary evaluations have indicated may have the greatest potential for error, burden the operator, have associated time pressures, or other constraints relative to operator workload.

Cognitive workload for each of the selected tasks is measured by the NASA-TLX (Reference 25), which provides a subjective measurement of workload. It consists of a multidimensional scale with six dimensions of factors related to mental workload. These six dimensions are defined in Table D.6-3.

Table D.6-3: NASA-TLX SCALE Definitions

Title	Endpoints	Descriptions
Mental Demand	Very Low/ Very High	How much mental and perceptual activity was required? Was the task easy or demanding, simple or complex, exacting, or forgiving?
Physical Demand	Very Low/ Very High	How much physical activity was required? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Very Low/ Very High	How much time pressure did you feel due to the rate or pace at which the task or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Perfect/ Failure	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	Very Low/ Very High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration Level	Very Low/ Very High	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

At the end of each selected task, test participants are given questionnaires (digital or paper-based) regarding the six NASA-TLX dimensions (Table D.6-3). For each question, the performer selects the area on the scale that they think most accurately describes their experience on the task that was just completed. Cognitive workload measures are recorded for the individual, task, and crew.

Since the term mental workload can be interpreted differently among respondents, personal opinion on what mental workload means to them is taken into the final calculation of the NASA-TLX score. This is done by deriving an overall workload score for each task based on a weighted average of ratings within each participant on the six subscales.

To obtain weights for each of the six workload dimensions per operator/per task, pair-wise comparisons are made between each of the dimensions. This is accomplished by using follow-up questions in which two dimensions are both displayed, and the operator is asked to choose which of the two dimensions contributed more to the workload for that task.

When the weights are applied to the results of the initial operator ratings for each of the six dimensions, a measure of overall cognitive workload is derived.

For the ISV, workload assessment is directed at confirming that previous efforts to address concerns have resulted in acceptable workload for the operators.

Levels of mental workload occur along a spectrum. A zone of acceptability exists at the center of the spectrum along a figurative line with conditions of unacceptable levels of mental workload being at either end of the spectrum (high and low).

The zone of acceptability is guided by nuclear industry standards, operator perceptions of acceptability, and the theories and principles associated with mental workload. Dynamic scenarios have successfully been used to assess workload in many fields including nuclear power generation. Because of their intentional similarity to actual work conditions, dynamic scenarios are the most pragmatic way to approach the measurement of such a dynamic concept with a vast number of variables.

Initial zones of acceptability are established based on studies using the NASA-TLX tool. These zones are reviewed after the results of the HSI test and evaluations and revised as needed to reflect the potential differences experienced with using highly trained nuclear power plant operators in a control room environment.

Table D.6-4 shows [[ ]](a)(4)

Table D.6-4: NASA-TLX Workload Zones

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Additionally, cognitive workload is used to understand other integrated validation results. For example:

- Cognitive workload is used when evaluating situation awareness (and vice-versa) because the two measures have been found to have a significant inverse correlation with one another.
- During a scenario or task, operators could not perform procedures correctly and within established time constraints, and that task was recorded as having high/low cognitive workload for one or more of the operators. If this occurs, it may be determined that high/low cognitive workload contributed to the unacceptable performance.

Results of the workload assessments, along with resolutions to any identified concerns, are documented in a workload assessment report.

D.6.7.7 Ergonomic and Physiological Factors

Control room ergonomics using anthropometric data are evaluated as part of HSI development and HFE design verification to ensure compliance to the anthropometric guidelines contained in the HSI style guide. Later, the design implementation confirms the as-built design compliance with the expected ergonomic design.

System-specific and integrated validation testing confirms during simulation the adequacy of the HSI ergonomic design for the population of operators in a real plant.

Validation tests to ensure that no significant negative effect on crew performance occurs within the context of the integrated system. Validation tests also ensure that no problems arise during HSI use that may not have been evident when HSI elements were verified without reference to specific tasks.

Review of anthropometric and ergonomic data is done in conjunction with physical workload posture data. After test participants have been selected for ISV activities, physical measurements are taken of each participant using tape measures and/ or calibrated anthropometric tools. Physical measurements are selected from the areas shown in Table D.6-5.

Table D.6-5: Physical Measurement Areas

Stature	Thigh Thickness	Shoulder Grip Length
Eye Height	Upper Leg Length	Hand Length
Shoulder Height	Seat Length	Hand Breadth
Elbow Height	Knee Height	Foot Length
Hip Height	Seat Height	Foot Breadth
Knuckle Height	Shoulder Breadth	Span
Sitting Height	Hip Breadth	Elbow Span
Sitting Eye Height	Upper Arm Length	Vertical Grip Reach (standing)
Sitting Shoulder Height	Elbow-Fingertip Length	Vertical Grip Reach (sitting)
Sitting Elbow Height	Upper Limb Length	

Measurements for each participant are entered into an electronic database along with a unique participant tracking number. Physical measurements for each participant are used to supplement ergonomic observations, and self-report questionnaires are used to validate the ergonomics of the integrated system. If ergonomic issues arise for a test participant, that participant's physical measurements are referenced to better understand the problem.

Integrated validation testing focuses on the aspects of ergonomics as they apply to the integrated system of displays and controls. This is measured by how effectively operators use the integrated system. Effectiveness is measured using a combination of quantitative and qualitative measurements.

The following are recorded (along with time and task) by test personnel during simulation or using videotaped simulations:

1. Number of times the operator repositions to accomplish task (lateral, leaning, or standing/stooping)
2. Changing posture to see displays
3. Changing posture to move between controls or between displays and controls
4. Operator posture during tasks (using 5-point rating scale where 1 = very poor and 5 = very good)
5. Brief description of type of posture problem(s)
6. Written description of any additional significant ergonomic problems as identified by test personnel, such as:
    a. Visibility of displays is obstructed by operators reaching across displays to engage controls. This is especially important when working with fine motion controls and feedback from control input is provided through the obstructed display.
    b. Interference with controls is created by reaching for other controls (e.g., inadvertently pressing the keys on a keyboard when reaching for a control switch on panel).

Observation data is supplemented with post-scenario operator questionnaires and debriefs. Operators are asked to rate each ergonomic element using a 5-point rating scale (1 = very poor, 5 = very good). Questionnaire items include:

- Reach and accessibility of control devices
- Visibility of indications
- Distance
- Seating comfort (work surface height, chair adjustability, and overall level of comfort)
- Ease of control
- Ease of device manipulation
- Overall perception of system usability
- Overall satisfaction with workspace layout
- Additional comments

If ergonomic design of the physical panels and layout of elements in the control room degrade crew performance such that procedures could not be accomplished correctly and within time constraints by operators representing the range of physical measurements, the integrated design fails validation. These criteria are based on established operating procedures and timelines.

If ergonomic design of the HSI represents a risk to operator safety or well-being, an HED is entered into the HFEITS. This determination is based on established ergonomic guidelines and subject matter expert judgments. This is done in conjunction with workload analysis.

Beyond this, anthropometric and ergonomic data is used to better understand the results of other performance measures. Evaluation of this data is based on established ergonomic guidelines, expert judgment, and the HFE DRD.

D.6.8 Test Design

Test design is the process of developing the integrated validation test such that the required attributes for scenario assignment and the qualifications of the test personnel and participants permit the observation of integrated system performance in a manner that avoids or minimizes bias, confounds, and noise (error variance).

The coupling of crews and scenarios determines how the test participants experience the test scenarios.

D.6.8.1 Scenario Assignment

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]]$^{(a)(4)}$ To avoid potential confounding of the test data, it is important that a crew does not repeat the same scenario twice.

D.6.8.2 Scenario Sequencing

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D.6.8.3 Test Steps

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D.6.8.4 Briefing Management

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D.6.8.5 Briefing Participants

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D.6.8.6 Communication Scripts

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D.6.8.7 Interaction of Test Personnel with Test Participants

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D.6.8.8 Data Collection

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D.6.8.9 Test Personnel Training and Requisites

Test personnel (HFE observers) receive training prior to and during pilot testing that is similar to the training required for simulator instructors/evaluators. Training is completed before initiation of the integrated validation tests. Some components of this training include:

- Planning and coordinating simulator sessions
- Observing operator performance
- Evaluating operator performance
- Use and importance of test procedures
- Experimenter bias and the types of errors that might be introduced into test data through the failure of test personnel to accurately follow test procedures or interact properly with participants
- The importance of accurately documenting problems that arise while testing, even if due to test personnel oversight or error
- Test personnel conducting the scenario and operating the simulator are qualified as simulator operators and familiar with the capabilities of the applicable part-task simulator or full-scope simulator
- Importance of performing required peer checks while running the scenario so that the scenario is not invalidated due to insertion of the wrong malfunction or other simulator triggers

Training includes protocols such as when and how to interact with the crew during the simulation, non-intrusive locations, use of recording devices, and the development and use of observation tools for taking notes during the scenario. Additionally, training presents how to focus on the HSIs, procedures, or tasks of importance for the specific scenario.

D.6.8.10 Test Participants Training and Requisites

ISV requires comprehensive knowledge of the systems included in the test. This knowledge is attained through formal classroom and simulator training. After training is complete, a comprehensive examination covering the training received and job performance measures for system manipulations on the simulator are conducted to prove the success of the training. Test participants selected have completed sufficient specific training to exhibit an acceptably stable level of performance across trials.

Test participants used during the full-scope simulator integrated validation tests are trained as follows:

- Test participants that were previously licensed on other types of nuclear power plants are required to receive Natrium-specific systems training, procedure training and simulator training for familiarization with the controls for the specific Natrium systems.
- Test participants with no previous nuclear power plant OE are required to receive additional training for generic fundamentals. The formerly licensed personnel attend integrated plant simulator training with the new trainees to promote teamwork and allow the new trainees to benefit from their experience.
- All personnel receive COO training and a comprehensive operating test in the full-scope simulator before participating in the full-scope simulator V&V testing.

D.6.9 Pilot Testing

A pilot study is performed prior to the initiation of the V&V process in the simulator. This study tests the process for determining adequate design, determining the correct data collection techniques, and verifying appropriate testbed completeness and fidelity. Scenarios to be run during ISV are pilot tested prior to actual ISV testing.

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The operating crew personnel used for the pilot testing are not used as test participants to perform ISV testing; however, they may be used as test personnel during ISV. Test personnel used for the HFE ISV are actively involved with the pilot testing for the HFE ISV scenarios so that they are familiar with the actual test.

D.6.10 Data Analysis

Data analysis is conducted in accordance with the established four-tier hierarchical set of performance measures with the greatest weight placed on data coming from the highest performance measure tiers. Analysis is dependent on the type and quality of data that is acquired. Due to the variance in human behavior, there is variability across collected data. The distribution and degree of variance within the collected data informs which data analysis techniques can be performed on that data.

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For each tier, the performance measures and their associated criteria range from pass/fail decisive criteria at the highest significance level [[ ]]$^{(a)(4)}$ to the supplemental criteria level. [[

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To provide additional information, timelines and movement pattern diagrams for each crew are constructed for each simulated scenario using video recordings and visual observation records. Test participants may assist by interpreting videotaped sessions and interrelating recorded events with test data.

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Additional information is collected using test personnel observations regarding qualitative assessments of influencing factors such as lighting level, noise level, communication clarity, HSI information clarity, and other factors. These factors potentially influence detection, analysis, planning, and implementation of actions. The test personnel observations are used to understand results and data.

For performance measures used as pass/fail indicators, failed indicators are resolved before the design is validated. Where performance does not meet criteria for supplemental performance measures, the results are evaluated using the HED resolution process.

When making inferences and generalizations from observed test performance to estimated real-world performance, test personnel consider that actual performance is more variable than observed validation test performance. If a performance on a performance measure passes the acceptance criteria by a small margin, test personnel also document this as an HED.

D.6.10.1 Data Verification

Analysis inputs are verified by comparing test personnel observations to each other and by comparing personnel observations to the computer-generated event logs. Data analysis and the conclusions drawn are independently verified.

D.6.10.2 Establishing Convergent Validity

During data evaluation and analysis, convergent validity is established by comparing data from performance measures that are intended to measure the same or closely related aspects of performance. Performance measures with high convergent validity with one another provide highly correlated data for the construct being measured. [[

]]$^{(a)(4)}$ Likewise, (as discussed in Sections D.6.7.6.1 and D.6.7.7) posture data obtained from physical workload performance measures have a moderate to high association with related anthropometric data.

If instances occur where two performance measures intended to measure the same thing have no association, an HED is entered into the HFEITS.

D.6.10.3 Controlling for Bias

HFE subject matter experts and specialists control bias during evaluation stages of design and during HFE V&V. The intent is to eliminate sources of bias. When that is not possible, sources of bias are measured and included as additional predictors in statistical analysis to statistically control for bias. [[

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D.6.11 Human Factors Validation Outputs

The output from HFE validation and ISV testing is validation of the following:

- Integrated procedures
- Integrated HSIs
- Integrated training
- Integrated software design
- Personnel roles
- Staffing and qualifications

- Transition capability between HSIs and procedures
- Integrated system tolerance of individual HSI failures

The results of validation activities provide input for revision to procedures, HSI, training, software design, personnel roles, staffing, and qualifications. Validation conclusions are documented, including the bases for acceptable performance. Deficiencies and discrepancies identified throughout the V&V process by test personnel are documented and logged into the HFEITS as HEDs. Design specifications, procedures, and training are revised using inputs from V&V activities.

The limitations of validation testing are documented, along with considerations regarding the potential effects of these limitations on validation conclusions and design implementation. These include issues such as:

- Aspects of the tests that were not well controlled
- Differences between the test situation and actual operations, such as absence of productivity-safety conflicts
- Differences between the validated design and as-built design

If an ISV item cannot be fully validated during HFE V&V due to testing limitations or other complications, the process is extended to the plant itself, and accomplished during design implementation. In this case, the V&V team describes the validation to be performed, indicates the acceptance criteria, and documents the requirement in the V&V results summary report and in the HFEITS as an HED.

D.7 Human Engineering Discrepancy Management

HEDs are HFE discrepancies, deviations, and issues revealed during the V&V process. HEDs and HFE issues are managed using the HFEITS (Section 6.4).

The HFEITS functionalities are:

- Evaluation
- ID of appropriate solutions
- Verification that the solutions implemented address the issue
- Documentation/traceability of the issue

The following list summarizes HED types per activity, and additional information is found in each section of this plan.

- General HEDs
- HEDs not addressed during the V&V element extend the resolution process to the next project phases. For these instances, the V&V team describes the verification to be performed, indicates the HSI style guide and regulation criteria, and documents the requirement in the V&V results summary report and in the HFEITS.
- TSV HEDs
- Unsupported tasks
- Partially supported tasks

- HSI characteristics that do not match the personnel task requirements
- Presence of unnecessary HSI components
- HFE design verification HEDs
- Non-compliance with design requirements from HFE DRD
- Early validation and ISV HEDs
- Occurrences of significant sampling bias
- Scenarios events and task that result in common problems for test participants
- Acceptance criteria not met during validation testing

D.8 Results Documentation

The output results from TSV, HFE design verification, and ISV are documented after completing each activity. The HFE V&V activities are typically performed in portions as the inputs become available (e.g., one TSV result report for the Group View Display System software displays, one HFE design verification result report for a group of system displays, or one ISV result report containing just startup and shutdown scenarios). The results are documented in a set of result reports.

An HFE V&V results summary report explains the results and main conclusions from the activities, including:

- Sampling process results
- Conclusions from TSV, HFE design verification, and ISV by cross-referencing the individual result reports
- Summary of HED management

The following structure of deliverables shows a representative set of reports for the project activities:

1. TSV result report(s)
2. HFE design verification result report(s)
3. Early validation result report(s)
4. ISV procedure(s)* and result report(s)
5. HFE V&V results summary report

***Note**: An ISV procedure is an optional deliverable that gathers in one document the technical aspects and methods for the specific scenarios selected for validation. This document is elaborated in advance of the ISV providing inputs for the ISV test personnel. The ISV procedure mainly contains the sampling results, the event guide [[ ]]$^{(a)(4)}$, support timelines, testbed descriptions, performance measures, and acceptance criteria.

HED management is performed using the HFEITS tool, and the HFE issue and HED ID and disposition process described in Section 6.4. The HFE V&V results summary report includes HEDs identified during the HFE V&V. The report highlights the significant HEDs and includes those HEDS that are unresolved for future project phases, providing information to address them.

D.9 Questions for Performance Measures Assessment

D.9.1 Personnel Tasks

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D.9.2 Crew Communication and Coordination

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D.10 Human Factors Engineering Verification and Validation Process Map

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Figure D.10-1: Human Factors Engineering Verification and Validation Process Map

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