July 25, 2025

TP-LIC-LET-0419
Docket Number 50-613

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

Subject: Submittal of Approved TerraPower, LLC Topical Report: Human Factors Engineering Program Plan and Methodologies

References: 1. U.S. Nuclear Regulatory Commission, TerraPower, LLC - Final Safety Evaluation of Topical Report NAT-2965, Human Factors Engineering Program Plan and Methodologies Topical Report, Revision 1 (ML25085A267)

The U.S. Nuclear Regulatory Commission (NRC) provided the final safety evaluation for the TerraPower, LLC Natrium®[1] Topical Report, Human Factors Engineering Program Plan and Methodologies, in Reference 1. The topical report describes TerraPower's human factors engineering program and related methodologies.

Enclosures 2 and 3 to this letter provide the accepted version of the topical report with the additional content incorporated per the NRC staff request, designated NAT-2965-A.

The 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." An affidavit certifying the basis for the request to withhold Enclosure 3 from public disclosure is included as Enclosure 1. Proprietary material has been redacted from the report provided in Enclosure 2; redacted information is identified using [[ ]]$^{(a)(4)}$.

This letter and the associated enclosures make no new or revised regulatory commitments.

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

If you have any questions regarding this submittal, please contact Ian Gifford at igifford@terrapower.com.

Sincerely,

George Wilson
Senior Vice President, Regulatory Affairs
TerraPower, LLC

Enclosures:
1. TerraPower, LLC Affidavit and Request for Withholding from Public Disclosure (10 CFR 2.390(a)(4))
2. TerraPower, LLC Topical Report "Human Factors Engineering Program Plan and Methodologies," NAT-2965-A, Revision 1, Non-Proprietary (Public)
3. TerraPower, LLC Topical Report "Human Factors Engineering Program Plan and Methodologies," NAT-2965-A, Revision 1, Proprietary (Non-Public)

cc: Mallecia Sutton, NRC
Josh Borromeo, NRC
Nathan Howard, 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 Senior 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® 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: July 25, 2025

George Wilson
____

George Wilson
Senior Vice President, Regulatory Affairs
TerraPower, LLC

ENCLOSURE 2

TerraPower, LLC Topical Report
"Human Factors Engineering Program Plan and Methodologies,"
NAT-2965-A, Revision 1

Non-Proprietary (Public)

TerraPower, LLC
15800 Northup Way
Bellevue, WA 98008

A TerraPower & GE-Hitachi Technology

Topical Report

Human Factors Engineering Program Plan and Methodologies

NAT-2956-A

Revision 1

June 12, 2025

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

April 18, 2025

George Wilson
Vice President, Regulatory Affairs
TerraPower, LLC
15800 Northup Way
Bellevue, WA 98008

SUBJECT: TERRAPOWER, LLC – FINAL SAFETY EVALUATION OF TOPICAL REPORT NAT-2965, "HUMAN FACTORS ENGINEERING PROGRAM PLAN AND METHODOLOGIES TOPICAL REPORT," REVISION 1 (EPID NO. L-2023-TOP-0026)

Dear George Wilson:

By letter dated April 26, 2023, TerraPower, LLC (TerraPower) submitted Topical Report (TR) NAT-2695, "Natrium Human Factors Engineering Program Plan and Methodologies," Revision 0 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML23116A225), for the U.S. Nuclear Regulatory Commission (NRC) staff's review. The TR describes the Natrium Human Factors Engineering Program Plan, including related methodologies, and requests NRC staff review and approval to support referencing of the report in licensing documentation. By email dated on June 21, 2023, the NRC staff found that the TR provided sufficient information for the NRC staff to begin its detailed technical review (ML23167A476).

On May 28, 2024, the NRC staff transmitted an audit plan to TerraPower (ML24137A289) and subsequently conducted an audit of materials related to the TR from June 13, 2024, through August 6, 2024. The NRC issued the audit summary on November 15, 2024 (ML24271A174). On September 17, 2024, TerraPower submitted a revision of the TR (ML24261B926) to clarify portions of the TR as discussed in the audit summary.

The enclosed final Safety Evaluation (SE) is being provided to TerraPower, because the NRC staff has found NAT-2695, Revision 1, acceptable for referencing in licensing actions to the extent specified and under the limitations and conditions delineated in the TR and the SE. The final SE defines the basis for the NRC staff's acceptance of the TR.

The NRC staff requests that TerraPower submit to NRC staff an approved version of this TR within three months of receipt of this letter. The approved version should incorporate this letter and the enclosed SE after the title page. The approved version should include a "-A" (designating approved) following the TR identification symbol.

If you have any questions, please contact Roel Brusselmans at (301) 415-0829 or via email at Roel.Brusselmans@nrc.gov.

Sincerely,

/RA/

Joshua Borromeo, Chief
Advanced Reactor Licensing Branch 1
Division of Advanced Reactors and Non-Power
Production and Utilization Facilities
Office of Nuclear Reactor Regulation

Project No.: 99902100

Enclosure:
As stated

cc: TerraPower Natrium via GovDelivery

SUBJECT: FINAL SAFETY EVALUATION OF TOPICAL REPORT NAT-2965, "NATRIUM HUMAN FACTORS ENGINEERING PROGRAM PLAN AND METHODOLOGIES," REVISION 1 (EPID L-2023-TOP-0026) DATED: APRIL 18, 2025

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TERRAPOWER, LLC. – FINAL SAFETY EVALUATION OF TOPICAL REPORT NAT-2965, "NATRIUM HUMAN FACTORS ENGINEERING PROGRAM PLAN AND METHODOLOGIES," REVISION 1 (EPID L-2023-TOP-0026)

SPONSOR AND SUBMITTAL INFORMATION

Sponsor: TerraPower, LLC

Sponsor Address: 15800 Northup Way
Bellevue, WA 98008

Project No.: 99902100

Submittal Date: September 17, 2024

Submittal Agencywide Documents Access and Management System Accession No.:
ML24261B925

Brief Description of the Topical Report: On April 26, 2023, TerraPower, LLC (TerraPower) submitted topical report (TR) NAT-2965, "Natrium Human Factors Engineering Program Plan and Methodologies," Revision 0 [1], for review by the U.S. Nuclear Regulatory Commission (NRC) staff. The TR describes the Natrium Human Factors Engineering Program Plan (HFEPP), including related methodologies, and requests the NRC staff review and approval to support referencing of the report in licensing documentation.

By email dated June 21, 2023 [2], the NRC staff informed TerraPower that the TR provided sufficient information for the NRC staff to begin its detailed technical review [3].On May 28, 2024, the NRC staff transmitted an audit plan to TerraPower (ML24137A289), and subsequently conducted an audit of materials related to the TR from June 13, 2024, through August 6, 2024. On September 17, 2024, TerraPower submitted revision 1 of TR NAT-2965 [4]. The NRC staff issued the audit summary on November 15, 2024 [5].

In section 2.0 of the TR, "Requirements and Technical Basis," TerraPower states that the HFEPP creates a human factor engineering (HFE) program that is compliant with the requirements of Title 10 of the *Code of Federal Regulations* (10 CFR) 50.34(f)(2)(ii) and 10 CFR 50.34(f)(2)(iii). Additionally, TerraPower states that the HFEPP also considers relevant practices provided in both Institute of Electrical and Electronics Engineers (IEEE) 1023-2020, "IEEE Recommended Practice for the Application of Human Factors Engineering to Systems, Equipment, and Facilities of Nuclear Power Generating Stations and Other Nuclear Facilities" [6], and NUREG-0711, "Human Factors Engineering Program Review Model," revision 3 [7].

REGULATORY EVALUATION

The NRC staff reviewed whether the HFEPP and related methodologies described in the TR were consistent with the relevant regulations and guidance. The key regulations, guidance, and standards discussed by TerraPower in the TR include:

- 10 CFR 50.34(f)(2)(ii), which states, in part, "establish a program, to begin during construction and follow into operation, for integrating and expanding current efforts to improve plant procedures. The scope of the program shall include emergency procedures, reliability analyses, human factors engineering, crisis management, operator training…"
- 10 CFR 50.34(f)(2)(iii), which states, in part, "provide, for Commission review, a control room design that reflects state-of-the-art human factor principles prior to committing to fabrication or revision of fabricated control room panels and layouts"
- NUREG-0700, "Human-System Interface Design Review Guidelines," revision 3 [8]
- NUREG-0711, "Human Factors Engineering Program Review Model," Revision 3
- NUREG-1764, "Guidance for the Review of Changes to Human Actions," revision 1 [9]
- IEEE 1023-2020, "IEEE Recommended Practice for the Application of Human Factors Engineering to Systems, Equipment, and Facilities of Nuclear Power Generating Stations and Other Nuclear Facilities"
- Electric Power Research Institute, EPRI 3002004310, "Human Factors Guidance for Control Room and Digital Human-System Interface Design and Modification" [10]

Additionally, "Kemmerer Power Station Unit 1 Preliminary Safety Analysis Report," revision 0, [11], table 1.4-4, "Applicability of TMI-Related Requirements," identifies, in part, the following regulations of 10 CFR 50.34(f) as having applicability to the proposed Natrium design.[1] Multiple subsections of 10 CFR 50.34(f) apply to HFE, including:

- 10 CFR 50.34(f)(2)(ii) for procedures,
- 10 CFR 50.34(f)(2)(iii) for HFE in the control room,
- 10 CFR 50.34(f)(2)(iv) for safety parameters display system,
- 10 CFR 50.34(f)(2)(v) for status of safety systems,
- 10 CFR 50.34(f)(2)(xi) for relief and safety valve indication,
- 10 CFR 50.34(f)(2)(xvii) for containment related indications,
- 10 CFR 50.34(f)(2)(xviii) for core cooling indications,
- 10 CFR 50.34(f)(2)(xix) for instrumentation to monitor post-accident plant conditions,
- 10 CFR 50.34(f)(2)(xxvi) for leakage control and detection,
- 10 CFR 50.34(f)(2)(xxvii) for radiation monitoring, and
- 10 CFR 50.34(f)(3)(i) for operating experience.

Furthermore, in reviewing the HFEPP, the NRC staff also considered the following additional regulations:

- 10 CFR 50.54(k) through (m), which address licensed operator staffing requirements;
- 10 CFR 50.120, which addresses training requirements for various plant staff categories;

[1] Combined Operating License (COL) applicants that wish to reference the topical report should describe how the content of the report has been assessed and, as needed, been supplemented in order to adapt its usage from the context of a Construction Permit/Operating License facility application process to that of a COL application process.

- 10 CFR 55.4, which defines a systems approach to training and its associated elements;
- 10 CFR 55.45(b), which addresses the administration of operating tests; and
- 10 CFR 55.46, which addresses the requirements for simulation facilities.

Because TerraPower applied the licensing modernization project in the construction permit application for its proposed Natrium reactor, the NRC staff also reviewed the HFEPP against the applicable criteria in DANU-ISG-2022-05, "Advanced Reactor Content of Application Project chapter 11, Organization and Human-System Considerations' Interim Staff Guidance" [12].[2]

TECHNICAL EVALUATION

The NRC staff compared the TR to the relevant[3] review criteria in NUREG-0711 to gain reasonable assurance that the HFEPP complies with the HFE regulations cited above. The HFE regulations include a requirement that the applicant provide a control room design that reflects state-of-the-art human factors (HF) principles so that the HFE design will support plant personnel in the safe operation of the plant.

NUREG-0711 describes a systematic method for developing a control room HFE design that complies with the HFE regulations. The method includes four general activities: (1) planning and analysis, (2) design, (3) verification and validation (V&V), and (4) implementation and operation. These four general activities consist of 12 HFE program elements, which together provide for the successful integration of human characteristics and capabilities into nuclear power plant design, as shown below:

- Planning and analysis: (1) HFE program management, (2) operating experience review (OER), (3) functional requirements analysis (FRA) and function allocation (FA), (4) task analysis (TA), (5) staffing and qualifications, and (6) treatment of important human actions (IHAs)
- Design: (7) human-system interface (HSI) design, (8) procedure development, and (9) training program development
- V&V (10)
- Implementation and operation: (11) design implementation and (12) human performance monitoring

The evaluation in this SE is organized according to these 12 elements. The NRC staff conducted a "bottom-up" review by assessing the relevant review criteria associated with each of the 12 elements in NUREG-0711. In conducting this review, the NRC staff recognize that, while NRC review plans generally describe acceptable means of meeting the regulations, they

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[2] TerraPower, on behalf of US SFR Owner, LLC (USO), submitted a construction permit application on March 28, 2024 for a Natrium reactor plant (ML24088A059). The NRC staff's review of this application is ongoing.

[3] Not all of the relevant review criteria in NUREG-0711 can be evaluated by the NRC staff at the construction permit application phase for Natrium that exists at the time of this evaluation. The information contained in the TR generally corresponds to implementation plans (IPs), as described under NUREG-0711 and describes the methods to be used, but not the resulting outputs and design stemming from implementation of those methods. A subsequent operating license application (OLA) is expected to be accompanied by the relevant results summary reports (RSRs) described under NUREG-0711 and a complete assessment of the HFE program for the purposes of determining compliance with 10 CFR 50.34(f)(2)(iii) may only occur at that point. Consistent with this, the evaluation of certain criteria is noted as being deferred until the OLA review when the necessary information will be available.

do not necessarily describe the only means of doing so and, therefore, applications may deviate from the acceptance criteria of a review plan such as NUREG-0711. However, where such differences exist, the NRC staff expect that an application will discuss how the proposed alternative provides an acceptable method of complying with relevant regulations that underlie the corresponding review plan acceptance criteria. At the same time, the degree to which the NRC staff applies the methodology of a review plan will reflect the specific circumstances of individual applications, with the factors that are considered when determining the depth of a review including both risk importance and safety significance. Additionally, it should be noted that the criteria of NUREG-0711 generally do not make distinctions between whether IPs or RSRs are being reviewed. Consistent with that lack of distinction, staff judgement has been applied regarding what is reasonable for a review that is limited to the IP phase of the HFE process when development of RSRs has yet to occur (and, moreover, prior to the availability of detailed design information in an OLA).[4] Furthermore, certain criteria of NUREG-0711 are relevant only within the context of the modification of existing plants and, as such, these criteria were excluded from the scope of this review.[5]

1.0 HFE PROGRAM MANAGEMENT

The NRC staff's objective in the review of this element is to verify that the applicant has an HFE design team with the responsibility, authority, placement within the organization, and composition to reasonably assure that the plant design meets the commitment to HFE. The NRC staff evaluated the HFEPP using the relevant review criteria in NUREG-0711, section 2.4, "Review Criteria," and the results of the NRC staff's evaluation are discussed below in sections 1.1 through 1.5. It should be noted that, per NUREG-0711, there is no associated RSR expected for this element.

1.1 <u>General Human Factors Engineering Program Goals and Scope (Criteria 2.4.1(1) – (6))</u>

1.1.1 HFE Program Goals (Criterion 2.4.1(1))

Criterion 2.4.1(1) identifies four general "human-centered" goals for an HFE program and states that, as the HFE program develops, the generic goals should be further defined and used as a basis for HFE tests and evaluations. The generic design goals provided by NUREG-0711 are:

1) personnel tasks can be accomplished within time and performance criteria
2) the HSIs, procedures, staffing/qualifications, training, and management and organizational arrangements support personnel situation awareness
3) the design will support personnel in maintaining vigilance over plant operations and provide acceptable workload levels, i.e., minimize periods of under- and over-load
4) the HSIs will minimize personnel error and will support error detection and recovery capability

The HFEPP defines the following design goals in section 1.1, "Purpose," of the TR:

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[4] The HFEPP described in the TR represents only HFE IPs for Natrium. Consistent with this, the need for applicants or licensees who reference the TR to make relevant RSRs available to support staff review of an OLA is addressed in the "Limitations and Conditions" section of this evaluation.
[5] NUREG-0711 explicitly identifies which criteria apply only to plant modifications and, as such, discussion of those specific criteria is not reproduced within this evaluation because they are not applicable to this review.

1) personnel tasks are accomplished within the evaluated time frame and performance criteria
2) information systems support a high degree of situation awareness of the state of the plant and actions required
3) allocation of function (AOF) maintains human vigilance and provides acceptable workload levels that minimize periods of human underload and overload
4) HSI minimizes error and provides for error detection
5) HSI design supports the capability of the operating crew to recover from previous decisions and actions that did not achieve intended results
6) 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

The NRC staff reviewed these goals described in the HFEPP and found they adequately address the four generic "human-centered" HFE design goals listed in criterion 2.4.1(1). Additionally, the NRC staff notes that section 5 of the TR describes how individual HFE elements implement and verify these HFE design goals during the design process. For example, section 5.4, "Staffing," of the TR discusses that staffing analysis is further confirmed through workload analysis and evaluated using mock-ups, modeling, or simulation, as appropriate. Additionally, section 5.10, "Human Factors Verification and Validation," of the TR discusses integrated system validation (ISV), which includes both the validation that important personnel tasks can be accomplished within required time frames as well as the verification that crew situational awareness and workload levels remain acceptable. Separately, section 5.5, "Treatment of Important Human Actions," of the TR discusses that human reliability analysis (HRA) is conducted as part of the development of a probabilistic risk analysis (PRA) and evaluates the potential for, and mechanisms of, human error that may affect plant safety with the HFE design (including HSIs) being used as an input to the definition of the performance shaping factors used in the HRA. Based on the above, the NRC staff has determined that TerraPower's plan for HFE program management addresses definition of the general HFE program goals and will use these goals as a basis for HFE tests and evaluations to assess whether the general HFE program goals have been met. Therefore, the NRC staff concludes that criterion 2.4.1(1) is met.

1.1.2 Assumptions and Constraints (Criterion 2.4.1(2))

Criterion 2.4.1(2) states that the applicant should identify the design assumptions and constraints (i.e., aspects of the design that are inputs to the HFE program).

Section 1.3 of the TR discusses that the initial staffing assumption aligns with the staffing requirements of 10 CFR 50.54(m) and that this assumption will be confirmed via the staffing analysis described under appendix C, "Human Factors Engineering Staffing Analysis Plan," of the TR. Additionally, section 1.3 of the TR states that no further assumptions have been identified with applicability to the overall HFE program and that any assumptions made during the design process when inputs are either not available or have not yet been confirmed will subsequently be confirmed by way of the design and testing program. Furthermore, section 1.3 of the TR states that no constraints have been identified that would apply to the HFE program in general. Based on the above, the NRC staff has determined that TerraPower's plan for HFE program management adequately identifies both design assumptions and constraints and, therefore, concludes that criterion 2.4.1(2) is met.

1.1.3 Human Factors Engineering Program Duration (Criterion 2.4.1(3))

Criterion 2.4.1(3) states that the applicant's HFE program should be in effect at least from the start of the design cycle through completion of the initial plant startup test program. Consistent with this, section 1.4 of the TR states that "the HFE program will be in effect from the start of the conceptual design cycle though completion of the initial plant startup test program, with the Human Performance Monitoring Program specified and active before initial fuel loading." The NRC staff has determined that TerraPower's plan for HFE program management adequately addresses the duration of the program and, therefore, concludes that criterion 2.4.1(3) is met.

1.1.4 Human Factors Engineering Facilities (Criterion 2.4.1(4))

Criterion 2.4.1(4) states that the applicant's HFE program should cover the main control room (MCR), remote shutdown facility, technical support center (TSC), emergency operations facility (EOF), and local control stations (LCSs). However, applicants may apply the elements of the HFE program in a graded fashion to facilities other than the MCR and remote shutdown facility, providing justification in the HFE program plan. The NRC staff notes that while this criterion discusses the TSC and EOF, the specific emergency facilities associated with Natrium will be defined within the emergency plan that will accompany an OLA.

Section 1.2, "Scope," of the TR states that the HFEPP applies to Nuclear Island (NI)-related HSIs including those at the following locations:

1) MCR
2) Remote Shutdown Complex (RSC)
3) Local controls
4) Emergency support facilities

TerraPower describes within section 1.2 of the TR that control and monitoring of both NI and Energy Island (EI) equipment is performed from HSIs in the MCR, with the layout and interface of both NI and EI workstations being of the same general design within an integrated overall MCR design. However, TerraPower states that the EI itself is not included within the scope of the HFEPP, with the justification being that no EI systems, structures, and components (SSC) "…are required to (1) respond to mitigate any events impacting the NI, (2) support safety-related, SSCs, or (3) ensure defense-in-depth adequacy." The NRC staff previously evaluated key implications of the separation of the NI and EI portions of the Natrium design, as documented under "Final Safety Evaluation of Topical Report NATD-LICRPRT-0001, "Regulatory Management of Natrium Nuclear Island and Energy Island Design Interfaces," [13] and notes that TerraPower's characterization regarding the significance of EI operations to NI safety is generally consistent with those prior staff conclusions. Based upon that, the NRC staff determined that the application of HFE within the context of the EI is not of significance because human performance within that location is not reasonably expected to influence Natrium safety outcomes in an appreciable manner and, accordingly, that TerraPower's exclusion of the EI from the scope of the HFEPP is reasonable.

Section 1.2 of the TR further describes that the application of HFE is graded based on nuclear safety, personnel safety, and asset protection considerations to apply greater rigor to those human interactions that are of higher importance from a standpoint of safety or hazards. The NRC staff notes that this approach represents a difference from the criterion of NUREG-0711 in that it involves grading HFE in a manner that is broader than what the criterion assumes. The NRC staff then considered whether this broader application of a graded HFE methodology was appropriate.

The staff notes that section 3.1, “Risk Level Determination,” of the TR describes that HFE is graded based upon three possible levels of application, **[[**

]] Section 3.2, “Human Factors Engineering Application Level Determination,” of the TR discusses that **[[**

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The NRC staff notes that NUREG-1764 provides a review framework under which the NRC staff use a combination of risk-informed and deterministic criteria to establish a graded level of HFE review for a given application. The combination of quantitative and qualitative insights can result in a staff review that ranges from a very comprehensive and rigorous HFE review all the way to essentially no HFE review at all. While NUREG-1764 is guidance to the NRC staff, versus an applicant or licensee, used generally for its review of license amendment requests, versus construction permit or operating license applications, the NRC staff notes that the fundamental principles involved remain relevant in either context. That is, greater HFE focus should be placed on human actions (HAs) that are of higher risk importance and safety significance. Thus, the NRC staff has determined that the fundamental approach of grading the application of HFE based upon safety and risk insights is consistent with existing, accepted practices.

Based on the above, the NRC staff has determined that the scope of the HFEPP covers facilities equivalent to those described within the review criterion and that the described exception (i.e., the EI) is justified. Additionally, the NRC staff has determined that, while TerraPower’s HFE grading approach is more extensive than that addressed by the criterion, the difference has been adequately justified and is consistent with practices that the NRC has found to be acceptable under NUREG-1764. Accordingly, the NRC staff concludes that the HFEPP meets criterion 2.4.1(4).

1.1.5 Human-System Interfaces, Procedures, and Training (Criterion 2.4.1(5))

Criterion 2.4.1(5) states that the applicant’s HFE program should address the design of HSIs and identify inputs to the development of procedures and training for all operations, accident management, maintenance, test, inspection, and surveillance tasks that operational personnel will perform or supervise. In addition, the HFE design process should identify training program input for instrumentation and control (I&C) technicians, electrical maintenance personnel, mechanical maintenance personnel, radiological protection technicians, chemistry technicians, and engineering support personnel. Any other personnel who perform tasks directly related to plant safety also should be included.

TerraPower describes the HSI design element of the HFE program in section 5.7, “Human-System Interface Design,” of the TR. The NRC staff notes that this element is incorporated into a broader HFE process in a manner that is generally consistent with the structure described by NUREG-0711. Section 5.7.8, “Human Factors Human-System interface Design Output,” of the TR states that the detailed HSI design feeds into the development of the simulator for training and the validation of procedures. Section 5.8, “Procedure Development,” of the TR describes that the procedure development plan (PDP) addresses procedures for the operations, maintenance, and inspection/testing of the plant. TerraPower also states in section 5.9, “Training and Qualification Program Development,” of the TR that a training program development plan (TPDP) is established to specify a systems approach to training (SAT)-based training process, with the approach being applied to positions included in the minimum staff complement. Additionally, TerraPower states that the TPDP addresses the guidance provided in Regulatory Guide (RG) 1.8, “Qualification and Training of Personnel for Nuclear Power Plants,” revision 4 [14], which endorses American National Standards Institute (ANSI) /American Nuclear Society (ANS)-3.1-2014, “Selection, Qualification, and Training of Personnel for Nuclear Power Plants” [15]. The NRC staff notes that ANSI/ANS-3.1-2014, with certain exceptions identified under RG 1.8, generally addresses the categories of personnel included within this criterion.

Based on the above, the NRC staff has determined that TerraPower’s plan for HFE program management addresses the design of the HSIs and will input that design into the procedures and training programs. The NRC staff, therefore, concludes that criterion 2.4.1(5) is met.

1.1.6 Personnel (Criterion 2.4.1(6))

Criterion 2.4.1(6) states that the applicant’s HFE program should consider operations staffing and qualifications, including licensed control room operators as defined in 10 CFR Part 55, “Operators’ Licenses”; non-licensed operators; shift supervisors; and shift technical advisors.

TerraPower states in section 5.4 of the TR that a staffing analysis process systematically determines the minimum staff complement. Appendix C of the TR describes the HFE staffing analysis plan. **[[**

]] However, the NRC staff notes that the shift technical advisor position (STA) is not discussed within this appendix. During the audit, TerraPower clarified that they will request an exemption in conjunction with the OLA to omit the STA, with HFE program activities under the HFEPP serving to provide support for the justification of this requested exemption. The NRC staff makes no conclusions about the STA or the appropriateness of a potential exemption as part of this SE.

From a qualifications standpoint, TerraPower states in section 5.9 of the TR that the TPDP addresses the guidance provided in RG 1.8, which endorses ANSI/ANS-3.1-2014. The NRC staff notes that ANSI/ANS-3.1-2014, with certain exceptions identified in RG 1.8, generally addresses the categories of personnel included within this criterion. Therefore, the NRC staff has determined that the HFEPP meets criterion 2.4.1(6), except for addressing STA staffing. The NRC staff has determined that it will be necessary for a future OLA applicant to either address STA staffing or provide an adequate justification to support the omission of the STA from the staffing model, including any associated exemption request(s); this is addressed in the "Limitations and Conditions" section of this evaluation.

1.2 HFE Team and Organization (Criteria 2.4.2(1)-(4))

1.2.1 Responsibility of the Human Factors Engineering Team (Criterion 2.4.2(1))

Criterion 2.4.2(1) lists activities the applicant's HFE team should be responsible for performing. These activities include developing HFE plans, overseeing and reviewing all activities in HFE design, and assuring that all HFE activities comply with the HFE plans and procedures. Section 4 of the TR describes the roles and responsibilities of the HFE organization. The NRC staff reviewed this section of HFEPP and determined that the responsibilities of the core HFE team, which broadly include establishing and performing the activities of the HFEPP, adequately address those listed in criterion 2.4.2(1). The NRC staff has determined that TerraPower's plan for HFE program management addresses the establishment of a specific entity to be responsible for the applicant's HFE design and, therefore, concludes that criterion 2.4.2(1) is met.

1.2.2 Organizational Placement and Authority (Criterion 2.4.2(2))

Criterion 2.4.2(2) states that the applicant should describe the primary HFE organization(s) or function(s) within the engineering organization designing the plant. The organization should be illustrated to show organizational and functional relationships, reporting relationships, and lines of communication. The applicant also should address necessary transitions between responsible organizations and how the HFE team has the authority and appropriate organizational placement to reasonably assure that all its areas of responsibility are completed; to identify problems in establishing the overall plan; and to control further processing, delivery, installation, or use of HFE products until the disposition of a nonconformance, deficiency, or unsatisfactory condition is resolved.

Section 4.0 of the TR states that the HFE organization is comprised of both a core HFE team and an extended team, with the extended team including members from other disciplines within the engineering design team. Within the HFE core team, a technical lead is identified who, in part, acts as the contact point for schedule development, integration, and management. The extended team membership is distributed throughout the design organization and provides expertise to the core HFE team as needed.

Section 4.1.3 of the TR states that the TerraPower organization will use established processes and procedures for the identification and resolution of HFE-related issues. Regarding organizational structure, an HFE technical lead is described as coordinating design activities with a TerraPower HFE program owner who provides an oversight function. The HFE program owner has responsibly within the TerraPower design organization for ensuring that any HFE-related concerns are reported, processed, and resolved. The TerraPower HFE program owner, in turn, reports to a senior manager that acts as both the senior-level advocate for HFE and technical design authority. Additionally, it is described that while specific reporting relationships are subject to change, the HFE program will continue to be represented by a TerraPower senior manager who would be the design authority.

During the audit, TerraPower clarified that GE Hitachi staffs the core HFE team (to include the HFE technical lead role), as well as related reporting relationships.

Because the HFE team has been given the responsibility for the HFE design as discussed under criterion 2.4.2(1) and because the HFE program owner has responsibly within the TerraPower design organization for ensuring that any HFE-related concerns are reported, processed, and resolved, the NRC staff has determined that the HFE team has adequate authority and organizational placement and, accordingly, concludes that criterion 2.4.2(2) is met.

1.2.3 Composition and Expertise (Criterion 2.4.2(3))

Criterion 2.4.2(3) states that the applicant's HFE design team should include the expertise described in the appendix to NUREG-0711 (i.e., "Composition of the HFE Design Team"). The NRC staff reviewed the HF organization description provided under section 4 of the TR, including the described roles, qualifications, and responsibilities. Section 4.1.1 of the TR describes that the HFE team is comprised of both a core team and an extended team. Regarding the expertise included within the HFE team, section 4.1.1 of the TR states the following:

> The HFE team, as an entity, satisfies the professional experience qualifications described in… 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.

Section 4.2 of the TR describes that the composition of the extended team is adapted from NUREG-0711 and states, in part, that:

> The qualification and experience requirements for the individuals supporting as extended members of the HFE team are determined by the performer's quality program and related procedures. Plant procedures and personnel training are developed in accordance with the licensee's administrative procedures, therefore, these roles are not summarized herein.

During the audit, TerraPower provided clarifications regarding the differences between the composition, qualifications, and experience of their HFE team versus that of the generic approach described by NUREG-0711.

The NRC staff notes that the TR describes a scope of roles, qualifications, and responsibilities for the HFE team that is generally consistent with the generic model presented under NUREG-0711 and that the differences between the approach described under the TR and that discussed within NUREG-0711 are reasonable. Based on the above, the NRC staff has determined that the applicant's HFE team includes adequate expertise and that the application conforms to this criterion. Therefore, the NRC staff concludes that criterion 2.4.2(3) is met.

1.2.4 Human Factors Engineering Team Staffing (Criterion 2.4.2(4))

Criterion 2.4.2(4) states that the applicant should describe team staffing in terms of job descriptions and assignments of team personnel. The NRC staff reviewed the HF organization description provided under section 4 of the TR (including the overall roles and responsibilities of team members) as part of the evaluation of criterion 2.4.2(3). Under that evaluation, the NRC staff determined that the applicant's overall plan for HFE team composition is adequate because the HFE team, as described in the TR, will include sufficient expertise. During the audit, TerraPower further clarified that GE Hitachi staffs the core HFE team, to include the HFE technical lead role. This HFE technical lead coordinates design activities with the TerraPower HFE program owner who, in turn, provides oversight. The NRC staff has determined that the applicant has addressed team staffing in terms of job descriptions and assignments of team personnel and, therefore, concludes that criterion 2.4.2(4) is met.

1.3 HFE Processes and Procedures (Criteria 2.4.3(1)-(6))

1.3.1 General Process Procedures (Criterion 2.4.3(1))

Criterion 2.4.3(1) states that the applicant should identify the process through which the team will execute its responsibilities and include procedures for governing the internal management of the team, making decisions on managing the HFE program, making HFE design decisions, controlling changes in the design of equipment, and reviewing HFE products.

Section 4.1.1 of the TR describes that the HFE technical lead provides both technical and programmatic oversight and review, in addition to acting as the contact point for schedule development, integration, and management. Additionally, section 4.1.2 states that "…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." Section 4.1.3 of the TR states that the HFE technical lead coordinates design activities with a TerraPower HFE program owner who, in turn, provides an oversight function. The TerraPower HFE program owner reports to a senior manager that acts as the technical design authority. Additionally, it is stated that while specific reporting relationships are subject to change, the HFE program will continue to be represented by a TerraPower senior manager who will be the design authority. During the audit, TerraPower clarified that GE Hitachi staffs the core HFE team, to include the HFE technical lead role. This HFE technical lead coordinates design activities with the TerraPower HFE program owner who, in turn, provides oversight.

Section 6.1 of the TR describes that the HFE program will be executed in accordance with procedures that include processes for HFE-related design and project decisions, acceptance of engineering products from suppliers, and design change control. It also states that the companies supporting Natrium HFE will work under their respective programs, plans, and procedures. Specifically, the procedures utilized by GE Hitachi in implementing HFE-related work are governed by NEDO-11209-A, "GE Hitachi Nuclear Energy Quality Assurance Program Description," revision 17 [16], and includes those procedures related to the design, review, and retention of engineering products, as well as for workforce planning, scheduling, and project management. Additionally, the TR states that supporting procedures related to personnel qualification, technical training, and proficiency that support making resource assignments are included within this scope as well.

During the audit, TerraPower clarified that they will generate the procedures for execution of the Natrium design for Kemmerer, Unit 1, and that these procedures are governed by TP-QA-PD-0001, "TerraPower QA Program Description," revision 14-A [17]. Additionally, TerraPower further clarified that the HFE core team members will also work under their respective company procedures for workforce planning, scheduling, and project management.

Based on the above, the NRC staff has determined that TerraPower's plan for HFE program management identifies the processes through which the HFE team will execute its responsibilities and will include procedures for HFE team activities. Therefore, the NRC staff concludes that criterion 2.4.3(1) is met.

1.3.2 Process Management Tools (Criterion 2.4.3(2))

Criterion 2.4.3(2) states that the applicant should identify the tools and techniques the team members use to verify that they fulfill their responsibilities. The TR identifies the following tools and techniques the HFE team members use for this verification:

- HFE Databases: Appendix A, "Human Factors Engineering Allocation of Function and Task Grading Methodology," of the TR contains an example of a "Allocation of Function and Task Grading Data Sheet," **[[** **]]** Appendix B, "Human Factors Engineering Task Analysis and Human-System Interface Design Methodology," of the TR contains an example of the data collection forms **[[** **]]** Additionally, examples were also provided of a task-level support, job design, workload, and workplace block template, as well as an HSI task support inventory template and trade-off evaluation form (i.e., Pugh Matrix).

- Verification Checklists: Appendix B of the TR contains examples of an HFE performance test methods and measures form, a usability questionnaire form, and a HF engineer observation form. Additionally, examples are also provided of a HF design evaluation checklist and a HF task support evaluation checklist. Appendix C of the TR contains an example of a timeline analysis chart and also discusses the development of both an expert panel staffing report and an expert panel staffing review report. Appendix D, "Human Factors Engineering Verification and Validation Plan," of the TR **[[** **]]**

- Human factors engineering issue tracking system (HFEITS) records: Section 8, "Human Factors Engineering Issue and Human Engineering Discrepancy Identification and Disposition," of the TR describes **[[**

]]

Based on the above, the NRC staff has determined that TerraPower's plan for HFE program management addresses identification of the tools and techniques the HFE team members use to verify that they have fulfilled their responsibilities and, therefore, concludes that criterion 2.4.3(2) is met.

1.3.3 Integration of HFE and Other Plant Design Activities (Criterion 2.4.3(3))

Criterion 2.4.3(3) states that the applicant should describe the process for integrating the inputs from other design work to the HFE program, and the outputs from the HFE program to other plant design activities. The applicant should also discuss the iterative aspects of the HFE design process.

The NRC staff notes that section 4.1 of the TR states that the "HF Operations/Maintenance" role of the HFE core team provides knowledge of operations, maintenance, and testing activities including technical requirements related to operational activities. Section 4.2 states that the "mechanical and electrical system engineering" discipline of the extended HFE team provides knowledge of the purpose, operating characteristics, and technical specifications of major plant systems. Section 4.2 also describes the "civil/structural engineering" discipline of the extended HFE team provides knowledge of the overall structure of the plant and design characteristics of locations that include the MCR and RSC. Additionally, this section also describes the "risk and reliability engineering" discipline of the extended HFE team as providing knowledge of plant component and system reliability/availability, plus assessment methodologies, to the HSI development activities.

The NRC staff further notes that in section 5 of the TR, TerraPower provides an overview of the elements that comprise the HFEPP and how they interrelate. The introduction to section 5 of the TR states that these "…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." Plant and system inputs are described, in part, as informing the FRA and FA (referred to as the AOF within the HFEPP), which section 5.2, "Functional Requirements Analysis," of the TR describes as then informing TA and HSI design activities. The HFE elements of the HFEPP are also described as being integrated with wider plant design processes. Section 5.11 of the TR, which addresses the design implementation element, includes the evaluation of deviations from the design during implementation and the resolution HEDs.

Based on the above, the NRC staff has determined that TerraPower's plan for HFE program management addresses the process for integrating the design activities (i.e., the inputs from other design work to the HFE program, and the outputs from the HFE program to other plant design activities) and discussed the iterative aspects of the HFE design process. Therefore, the NRC staff concludes that criterion 2.4.3(3) is met.

1.3.4 HFE Program Milestones (Criterion 2.4.3(4))

Criterion 2.4.3(4) states that the applicant should identify HFE milestones that show the relationship of the elements of the HFE program to the integrated plant design, development, and licensing schedule, as well as that a relative program schedule of HFE tasks should be available for review. The NRC staff notes that the TR describes an HFE program (i.e., the HFEPP) that is intended to be incorporated by reference into a subsequent facility licensing application (e.g., a construction permit and/or operating license application) and that specific dates for activities are not included within the TR itself. The NRC staff has determined that this represents an incomplete aspect of the NUREG-0711 review methodology and is addressed in the "Limitations and Conditions" section of this evaluation.

1.3.5 HFE Documentation (Criterion 2.4.3(5))

Criterion 2.4.3(5) states that the applicant should identify the HFE documentation items, such as RSRs and their supporting materials, and briefly describe them, along with the procedures for their retention and for making them available to the NRC staff for review.

The NRC staff notes that the TR contains IPs that address the methods that will be used to implement the HFEPP's elements of OER, FRA, AOF, staffing, treatment of important HAs, TA, HSI Design, procedures, training and qualification, HF V&V, design implementation, and human performance monitoring. In general, these IPs provide a description of the methods to be used and the documentation to be generated. NUREG-0711 explains that IPs and RSRs are the two primary types of applicant submittals that the NRC staff reviews. The NRC staff notes that no corresponding RSRs for the discussed IPs are available currently, which is addressed in the "Limitations and Conditions" section of this evaluation.

Section 6.1 of the TR describes that the companies supporting Natrium HFE will work under their respective programs, plans, and procedures. Specifically, the procedures utilized by GE Hitachi in implementing HFE-related work are governed by NEDO-11209-A and includes those procedures related to the retention of engineering products. Section 6.5, "Results," of the TR further discusses that RSRs and supporting documentation will be retained as required by the performer's quality assurance program, with TerraPower providing the RSRs for the NRC staff review. During the audit, TerraPower further clarified the specific details on their plans for retention of engineering documentation for HFE.

Based on the above, the NRC staff has determined that TerraPower's plan for HFE program management addresses procedures for the retention of HFE documentation items (specifically RSRs and their supporting materials) and that the review of the RSRs can be deferred until the review of an OLA. Therefore, the NRC staff concludes that criterion 2.4.3(5) is met.

1.3.6 Subcontractor Efforts (Criterion 2.4.3(6))

Criterion 2.4.3(6) states that the applicant should include HFE requirements in each subcontract contributing to the HFE program, periodically verify the subcontractor's compliance with HFE requirements, and describe milestones and the methods used for this verification. Section 5.7.4, "Human Factors Design Requirements Document and Human-Systems Interface Style Guide," of the TR states that the HFE design requirements document (DRD), or DRD source requirements, and the style specification are passed along to contractor suppliers for NI HSIs via the procurement process. In instances where there are "commercial-off-the-shelf" considerations the HFE team will work with the designer to comply with the HFE DRD or style specification or, alternatively, develop a justification for acceptability. Furthermore, section 5.7.4 of the TR states that the implementation of HFE requirements by suppliers is confirmed by means of the V&V process. Section D.4, "Sampling of Operational Conditions," of the TR discusses, in part, this aspect of the V&V process and states that "the sampling process includes equipment and interfaces provided by suppliers and sub-contractors as part of the sampling population."

During the audit, TerraPower clarified the various means by which the contractors and sub-contractors doing HFE-related work are tied into the Natrium HFE program.

Based on the above, the NRC staff has determined that TerraPower's plan for HFE program management addresses the methods by which HFE requirements will be provided to contractors, sub-contractors, and suppliers contributing to the HFE program, as well as the milestones and the methods that will be used to verify compliance with HFE requirements, and, therefore, concludes that criterion 2.4.3(6) is met.

1.4 <u>Tracking HFE Issues (Criteria 2.4.4(1)-(4))</u>

1.4.1 Availability (Criterion 2.4.4(1))

Criterion 2.4.4(1) states that the applicant should have a tracking system to address human factors issues that are known to the industry; identified throughout the life cycle of the HFE aspects of design, development, and evaluation; and deemed by the HFE program as HEDs. Section 8 of the TR states that the HFEITS is used to address HFE issues, including those issues specifically listed in criterion 2.4.4(1). The NRC staff has determined that the applicant has established a tracking system for HFE issues and, therefore, concludes that criterion 2.4.4(1) is met because.

1.4.2 Method (Criterion 2.4.4(2))

Criterion 2.4.4(2) states that the applicant should establish criteria for entering issues into the system and tracking issues until the potential for negative effects on human performance are reduced to an acceptable level. Section 8.1, "How to Identify Human Factors Engineering Issues and Human Engineering Discrepancy," of the TR describes that HFE issues are placed into the HFEITS when issues cannot be currently resolved through the normal HFE process and require tracking until the can be resolved. HEDs are described as being placed into HFEITS when a deviation from a human factors DRD requirement is discovered during design verification, when information and control requirements identified by TA have not been met by an HSI during task support verification (TSV), when HSIs are identified during TSV as not being needed to support personnel tasks, or when acceptance criteria are not met during ISV. Thus, the NRC staff has determined that the applicant established criteria for entering issues into the tracking system.

Section 8.2 of the TR discusses the methodology for prioritizing HFE issues and HEDs. **[[**

]]. Three priority levels are described as follows:

- Priority 1 (highest) corresponds to safety consequences and is associated with conditions (e.g., equipment, HSI, procedure, training, or staffing deviation, deficiency, or nonconformance) or adverse trends that have the potential to affect **[[**
]].

- Priority 2 (high) corresponds to plant or personnel performance effects and is associated with conditions or adverse trend that have the potential to affect **[[ ]]**.
- Priority 3 (low) corresponds to enhancements (of a nature neither involving safety consequences nor affecting performance) and is associated with conditions or adverse trends that deviate from the HFE DRD or HFE principles but do not involve safety or risk consequences.

Section 8.4 states that "…all HEDs that have been rated as Priority 1 or Priority 2 must be dispositioned through design change to correct the discrepancy and to address the human factors concern," as well as that "resolution of Priority 1 and 2 HEDs may not be deferred." Milestones before which Priority 1 and 2 HEDs must be dispositioned are also described (e.g., prior to ISV or design implementation). Beyond this, Priority 3 HEDs may instead be dispositioned through design change, deferment, or by means of a HF-justified exception, as determined by the HFE team.

NUREG-0711, section 11.4.4, "Human Engineering Discrepancy Review Criteria," contains guidance for determining which HEDs to correct such that possible negative impacts on human performance are reduced to an acceptable level. The NRC staff found the applicant's plan to track and resolve Priority 1 and 2 HEDs to be consistent with this guidance; therefore, the applicant will track HEDs that could have negative impacts on human performance until they have been resolved. Priority 3 HEDs do not have direct or indirect impacts on plant safety, plant performance or operability, so the NRC staff does not consider these types of issues to require resolution. Based on the above, the NRC staff has determined that TerraPower's plan for HFE program management addresses the establishment of criteria for tracking issues until the potential for negative effects on human performance is reduced to an acceptable level and, therefore, concludes that criterion 2.4.4(2) is met.

1.4.3 Documentation (Criterion 2.4.4(3))

Criterion 2.4.4(3) states that the applicant should document the actions taken to address each issue in the system, and if no action is required, this should be justified. Section 8 of the TR states that HFE issues and HEDs are placed into the HFEITS when specified criteria are met. The information that is documented includes the associated priority of the issue or HED. This section also describes the general types of information that is documented with regard to the resolution of issues and HEDs. This documentation is described as including, as applicable, justifications, verification results and methodology, test reports, acceptability conclusions, newly identified HEDs, and deferred resolutions. The NRC staff has determined that the applicant's method is acceptable because the actions taken to address issues and descriptions of the resolutions will be documented. Therefore, the NRC staff concludes that criterion 2.4.4(3) is met.

1.4.4 Responsibility (Criterion 2.4.4(4))

Criterion 2.4.4(4) states that the applicant's tracking procedures should describe individual responsibilities for logging, tracking, and resolving issues, along with the acceptance of the outcome.

Section 8 of the TR describes individual responsibilities for tracking issues. This sections states that HFEITS information is initially populated by the originator and updated by the issue owner. Issue owners also conduct any related cumulative effects analysis and determine if a change to

the priority of the affected HEDs is warranted. **[[**
]]. Issue owners also determine the means to check the adequacy of revision or disposition actions completed by assignees. Additionally, issue owners also assign and brief the individuals who implement HED resolution reviews, verifications, and validations. Individual roles are explained as they relate to the various HED resolution approaches. **[[**
]]. For HEDs that emerge during ISV, issue owners determine appropriate validation strategies using a graded approach, with the HF verifiers acting as the lead on retesting activities and documenting acceptability.
[[
]]. For deferrals, issue owners update HFEITS accordingly and ensure the HEDs are tracked to resolution.

Based on the above, the NRC staff has determined that TerraPower's plan for HFE program management addresses individual responsibilities for logging, tracking, and resolving HFE issues, as well as for determining the acceptability of outcomes, and, therefore, concludes that criterion 2.4.4(4) is met.

1.5 <u>Technical Program (Criteria 2.4.5(1)-(5))</u>

1.5.1 Status (Criterion 2.4.5(1)) and Schedule (Criterion 2.4.5(2))

Criterion 2.4.5(1) states that the applicant should describe the applicability and status of each of the HFE elements, and criterion 2.4.5(2) states that the applicant should provide a schedule for completing HFE activities that are unfinished at the time of application. The NRC staff found that the HFEPP describes programmatic activities associated with all the HFE elements described under criterion 2.4.5(1) and that no elements are identified as being non-applicable. Accordingly, the NRC staff concludes that the HFEPP meets criterion 2.4.5(1).

However, the NRC staff notes that the TR describes an HFE program (i.e., the HFEPP) that is intended to be incorporated by reference into a subsequent facility licensing application (e.g., a construction permit and/or operating license application) and that specific dates for HFE activities are not included within the TR itself. The NRC staff has determined that criterion 2.4.5(2) represents an incomplete aspect of the NUREG-0711 review methodology that is addressed in the "Limitations and Conditions" section of this evaluation.

1.5.2 Standards and Specifications (Criterion 2.4.5(3))

Criterion 2.4.5(3) states that the applicant's plan should identify and describe the standards and specifications that are sources of the HFE requirements.

In section 2.0 of the TR, "Requirements and Technical Basis," TerraPower describes "…the process requirements and technical basis inputs applicable to the creation, implementation, and maintenance of an HFE program." Section 2.0 of the TR states that the HFEPP considers relevant practices provided in both NUREG-0711, revision 3, and IEEE 1023-2020. Section 2.0 of the TR also states that specific HFE design and element areas also have other requirement and technical basis documents associated with them in the applicable sections of the TR. The NRC staff notes that a number of other guidance documents are referenced in conjunction with the various HFEPP elements described in the HFEPP, including ones produced by the NRC staff, International Atomic Energy Agency, U.S. Department of Energy, IEEE, and International

Electrotechnical Commission (IEC). The NRC staff has determined that the HFEPP identifies the references for the design-specific HFE requirements established by TerraPower for the HFE design. Accordingly, the NRC staff concludes that the HFEPP meets criterion 2.4.5(3).

1.5.3 Facilities, Equipment, Tools, and Techniques (Criterion 2.4.5(4))

Criterion 2.4.5(4) states that the applicant's plan should specify HFE facilities, equipment, tools, and techniques (such as laboratories, simulators, and rapid prototyping software) that the HFE program will employ. The applicant described the following HFE facilities, equipment, tools, and techniques used in the HFE program:

- HFE facilities and equipment: Section 5.7.6, "Human-System Interface Tests and Evaluations," of the TR states that a generic plant simulation model may be used for HSI development and usability testing until a site-specific system model becomes available, at which point tests and evaluations will be conducted using site-specific models. It is also stated that dynamic simulation will be used as a HF design tool for validation testing. Simulations are designed as either being conducted using a user interface through a computer-based workstation, a glass-top simulator, or a hardware-based simulator. Section 5.10 of the TR states that testing is iterative in nature and that once the design reaches a sufficient level of maturity, validation work can be conducted on a part-task simulator. The subsequent ISV is described as being performed on a high-fidelity simulator of the control area.

- Tools: Section 8 of the TR discusses that the HFEITS is used to capture both HFE issues and HEDs for the purposes of tracking and resolution. Appendix A of the TR describes the use of a workbook for documenting the results of AOF, task grading, and TA activities, while appendix B discusses the use of a workbook for TA and HSI design activities as well. **[[** **]]**. Appendix D, section D.6.1, "Human Factors Engineering Validation Inputs," discusses the use of a variety of tools for developing validations, including, in part, task narratives, timeline analyses, and workload analyses. Section D.6.3.2, "Human Factors Engineering Validation Data Collection Tools," describes the use of various observation tools and data collection forms for use during ISV, **[[** **]]**.

- Techniques: Section 3 of the TR describes an assessment methodology for use grading the application of HFE under certain elements addressed by the HFEPP. In section 5.7.6, TerraPower describes that iterative testing is to find and correct issues immediately in lieu of waiting for subsequent V&V activities. HSI test and evaluation employs techniques ranging from simple user questionnaire responses and comments to empirical, performance-based techniques. Other design techniques that are described include, in part, using drawings, physical or virtual mock-ups, and software-based 3D models.

The NRC staff has determined that the HFEPP describes equipment, tools, and techniques that represent an acceptable means of gaining user feedback that can be incorporated into the design as it evolves and, therefore, concludes that criterion 2.4.5(4) is met.

1.6 Overall Conclusion for the HFE Program Management Element

The NRC staff concludes that, subject to the limitations and conditions contained in this evaluation, TerraPower's plan for HFE program management, as described by the TR, is generally consistent with the relevant criteria of NUREG-0711.

2.0 OPERATING EXPEREIENCE REVIEW

The NRC staff's objective in the review of this element is to verify that the applicant will identify and analyze HFE-related problems and issues encountered in previous designs so that these problems and issues may be avoided in the development of the new design. This review also considers whether the applicant will retain the positive features of previous designs. The NRC staff evaluated the HFEPP using the relevant review criteria in NUREG-0711, section 3.4, "Review Criteria," and the results of the NRC staff's evaluation are discussed below in sections 2.1 through 2.2. The subsections below document the results of the NRC staff's evaluation. The NRC staff notes that, per NUREG-0711, an associated RSR is expected for this element, however, RSRs are not included as part of this HFEPP and will need to be submitted and reviewed as part of an OLA.

2.1 Scope (Criteria 3.4.1(1) – (5))

2.1.1 Predecessor/Related Plants and Systems (Criterion 3.4.1(1))

Criterion 3.4.1(1) states that the applicant's OER should include information about HF issues in the predecessor plant(s) or highly similar plants, systems, and HSIs. Section 5.1 of the TR states that the objective of the OER is to identify and analyze issues in earlier designs that are similar to the current ones in order to facilitate negative features associated with those predecessor designs being avoided while positive features are retained. Section 5.1 of the TR also describes that the OER report will include an HFE-focused literature review that covers prior deployments of similar reactor technologies. The NRC staff has determined that TerraPower's plan for OER addresses predecessor/related plants and systems and, therefore, concludes that criterion 3.4.1(1) is met.

2.1.2 Recognized Industry HFE Issues (Criterion 3.4.1(2))

Criterion 3.4.1(2) states that the applicant should address the HFE issues identified in NUREG/CR-6400, "Human Factors Engineering (HFE) Insights for Advanced Reactors Based Upon Operating Experience," [18]. Section 5.1 of the TR states that the OER report will address HFE issues identified in NUREG/CR-6400. The NRC staff has determined that TerraPower's plan for OER will include the HFE issues identified in NUREG/CR-6400 within its scope and, therefore, concludes that criterion 3.4.1(2) is met.

2.1.3 Related HSI Technology (Criterion 3.4.1(3))

Criterion 3.4.1(3) states that the applicant's OER should cover operating experience (OE) with the proposed HSI technology in the applicant's design. Section 5.1 of the TR states that the OER report will address OE related to the HSI technology that will be used to support those HAs included in both the safety analysis and in the PRA. The NRC staff has determined that TerraPower's plan for OER addresses related HSI technology and, therefore, concludes that criterion 3.4.1(3) is met.

2.1.4 Issues Identified by Plant Personnel (Criterion 3.4.1(4))

Criterion 3.4.1(4) states that applicant's OER should discuss issues identified through interviews with plant personnel based on their operating experience with plants or systems applicable to the new design. Section 5.1 of the TR states that the OER report will incorporate HFE-focused personnel interviews or questionnaires on previous deployments of the same reactor technology. The NRC staff has determined that TerraPower's plan for OER addresses the inclusion of issues identified by plant personnel and, therefore, concludes that criterion 3.4.1(4) is met.

2.1.5 Important Human Actions (Criterion 3.4.1(5))

Criterion 3.4.1(5) states that the applicant's OER should identify important HAs in the predecessor plants or systems and determine whether they remain important in the applicant's design. Section 5.1 of the TR states that the OER report will include the review of HAs from predecessor designs that are similar to HAs included in both the safety analysis and PRA. The NRC staff has determined that TerraPower's plan for OER addresses IHA and, therefore, concludes that criterion 3.4.1(5) is met.

2.2 Issue Analysis, Tracking, and Review (Criteria 3.4.2(1) – (4))

2.2.1 Operating Experience Review Process (Criterion 3.4.2(1))

Criterion 3.4.2(1) states that the applicant should discuss the administrative procedures for evaluating the operating, design, and construction experience, and for ensuring that applicable important industry experiences will be provided in a timely manner to those designing and constructing the plant.

Section 5.1 of the TR states that an OER report will be developed and that the objective will be to identify HFE issues to provide a basis for improving the plant design at the beginning of the design process. This includes the identification and analysis of issues from similar past designs to facilitate both the avoidance of negative features and the retention of positive ones. Additionally, it is also stated that OER outputs to the other HFE elements may influence the design process and design itself. During the audit, TerraPower stated that the OE gathered to support the Natrium HFE design was collected over many years of new nuclear design efforts and will also be updated with new sodium reactor OE at the start of HFE design activities. Section 6.5 of the TR states that RSRs addressing at least the minimum information stipulated in NUREG-0711 will be developed and that TerraPower will make these RSRs available for review by the NRC staff. The NRC staff notes that this RSR scope would be inclusive of the OER report.

Based on the above, the NRC staff has determined that TerraPower's plan for OER addresses the evaluation of relevant issues and operating experience to inform the design and, furthermore, that the details of how this review was conducted and its results can be evaluated by the NRC staff when the associated OER RSR is submitted in conjunction with an OLA.

2.2.2 Analysis Content (Criterion 3.4.2(2))

Criterion 3.4.2(2) states that the applicant should analyze issues to identify human performance issues and sources of human error, as well as design elements supporting and enhancing human performance. Section 5.7.4 of the TR states that, "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." Section B.2.2.1, "Review of System Relevant Operating Experience," of the TR describes the TA process as being informed by the review of OE. Section B.2.2.5.5, "Operating Experience Associated with Task," of the TR discusses **[[**

]] Additionally, section C.4, "Inputs," of the TR discusses that the staffing analysis uses input information from the OER, with focus on specific OE that is related to human performance issues. The NRC staff has determined that TerraPower's plan for OER addresses the analysis of human performance related issues and, therefore, concludes that criterion 3.4.2(2) is met.

2.2.3 Documentation (Criterion 3.4.2(3))

Criterion 3.4.2(3) states that the applicant should document the analysis of OE. Section 5.1 of the TR states that an OER report will be developed and that lessons learned from OE will provide a basis for design improvements. The NRC staff has determined that TerraPower's plan for OER addresses documentation of the analysis of OE and, therefore, concludes that criterion 3.4.2(3) is met.

2.2.4 Incorporation into the Tracking System (Criterion 3.4.2(4))

Criterion 3.4.2(4) states that the applicant should document each issue determined to be relevant to the design, but yet to be addressed, in the issue tracking system. Section 5.1 of the TR states that "operating experience issues relevant to the HFE design but not yet addressed are documented in the HFEITS." The NRC staff has determined that TerraPower's plan for OER addresses the documentation of unresolved issues within an issue tracking system and, therefore, concludes that criterion 3.4.2(4) is met.

2.3 <u>Overall Conclusion for the Operating Experience Review Element</u>

The NRC staff concludes that TerraPower's plan for OER, as described by the TR, is generally consistent with the relevant criteria of NUREG-0711. The associated results of this plan's implementation can be reviewed by the NRC staff when a future OER RSR is provided.

3.0 FUNCTIONAL REQUIREMENTS ANALYSIS AND FUNCTION ALLOCATION

Functional Requirements Analysis (FRA) is the identification of functions that must be performed to satisfy plant overall goals (e.g., safe operation, power generation). Function Allocation (FA) is the analysis of requirements for plant control and the assignment of control functions to personnel, system elements, and combinations of personnel and system elements. The NRC staff's objective in the review of this element is to verify that the plant's functions that must be performed to satisfy plant safety objectives will be defined, and the allocation of those functions to human and system resources will result in a role for personnel that takes advantage of human strengths and avoids human limitations. The NRC staff evaluated the HFEPP using the relevant review criteria in NUREG-0711, section 4.4, "Review Criteria," and the results of the NRC staff's evaluation are discussed below in sections 3.1 through 3.2. It should be noted that, per NUREG-0711, an associated RSR is expected for this element, however, RSRs are not included as part of this HFEPP and will need to be submitted and reviewed as part of an OLA.

3.1 Methodology (Criteria 4.4(1) – (2))

In NUREG-0711, section 4.4, criteria 4.4(1) – (2) address the methodology used for the FRA/FA processes. Criterion 4.4(1) focuses on ensuring a structured and documented methodology that reflects HFE principles and criterion 4.4(2) says that the processes should be performed iteratively.

Section 5.2 of the TR states that FRA defines functions that are traced to the principal design requirements of the plant. The overall process is described as including activities for elicitation, analysis, allocation, and documentation. This process yields an output document containing a complete list of functions, including their relevance to HFE, which are then input into the AOF process. Section 5.3 of the TR describes the AOF as establishing "…a plant control scheme that enhances plant safety and reliability by taking advantage of human and machine strengths and avoiding human and machine limitations." Objectives of the AOF process include establishing a design conducive to situational awareness and providing acceptable workload levels. The AOF process is described as first establishing an initial allocation based on expert input. The possible allocations are described to include human-only, machine-only, shared (i.e., human and machine), or backup (e.g., a human providing backup to a machine). The initial AOF is described as being iterated upon as the design process and testing progresses until the point at which a final AOF is established for ISV.

Appendix A of the TR details specifics of the AOF process. Section A.2.1, "Allocation of Function Definition," discusses that the AOF definition process incorporates both OE and subject-matter experts to consider how similar applications were allocated, as well as what performance resulted from those allocations. Section A.2.2, "Allocation of Function Definition," describes that the AOF evaluation process involves examining function and task groupings to assess allocations collectively and in an integrated environment via scenario development. Evaluations are then conducted to determine acceptability based on task performance, workload, and situation awareness. During the audit, TerraPower clarified how the AOF is iterated upon, as needed, as the design progresses. TerraPower also confirmed that, once the plant is turned over to the licensee, any evaluations or changes in the AOF would be implemented using the administrative procedures described in the "Kemmerer Power Station Unit 1 Preliminary Safety Analysis Report" (PSAR) [19].

Based on the above, the NRC staff has determined that TerraPower's plan for FRA and AOF describes a structured, documented methodology that will be performed iteratively and, therefore, concludes that criteria 4.4(1) – (2) are met. The evaluation of measures to ensure that the FRA and FA are updated, as needed, during the operations phase can reasonably be deferred until the review of an OLA.

3.2 Functional Requirements Analysis and Function Allocation Results (Criteria 4.4(3) – (8))

In NUREG-0711, section 4.4, criteria 4.4(3) – (4) focus on ensuring that the results of the FRA analysis are adequate, criteria 4.4(5) – (7) address the results of the FA, and criterion 4.4(8) addresses verification of completion. Specifically, criterion 4.4(3) provides specific properties that the plant's functional hierarchy should address. Criterion 4.4(4) focuses on identifying design requirements associated with the high-level plant functions identified in the plant's functional hierarchy. Criterion 4.4(5) states that the FA should identify the level of automation for each function as well as the technical bases for the allocation. Criterion 4.4(6) states that the FA should address primary actions taken by the operator as well as other operator actions, such as monitoring automation, detecting degradations/failures, and assuming manual control. Criterion 4.4(7) addresses the overall role of the operators while considering all functions allocated to them. Finally, criterion 4.4(8) focuses on verifying that the results of the FRA/FA are complete and have accomplished the objectives.

The NRC staff's evaluation of criteria 4.4(1) – (2) is also applicable for the evaluation of criteria 4.4(3)-(8) in that TerraPower's plan for FRA and AOF describes a structured, documented FRA/FA methodology that will be performed iteratively. For criteria 4.4(3)-(4), section 5.2 of the TR describes that the FRA defines functions that are based upon the principal design requirements of the plant and provides inputs into the AOF process. For criteria 4.4(5)-(6), section 5.3 of the TR describes that the AOF establishes how the plant will be controlled (e.g., allocations of human-only, machine-only, shared, or backup control) and is iterated upon as the design process and testing progresses. For criteria 4.4(7)-(8), section A.2.2 of the TR details how the AOF evaluation process involves examining task groupings to collectively assess allocations in an integrated, scenario environment, with evaluations being conducted to determine acceptability based on task performance. The NRC staff has determined that the HFEPP includes plans for developing a functional hierarchy, identifying related requirements, allocating functions, accounting for human roles in backing up functions allocated to machines, describing the overall role of personnel, and for completing FRA/FA processes. Therefore, the NRC staff concludes that criteria 4.4(3) – (8) are met.

3.3 Overall Conclusion for the FRA/FA Element

The NRC staff concludes that TerraPower's plan for FRA/FA, as described by the TR, is generally consistent with the relevant criteria of NUREG-0711. The associated results of this plan's implementation can be reviewed by the NRC staff when a future FRA/FA RSR is provided.

4.0 TASK ANALYSIS

Task analysis (TA) identifies the tasks that plant personnel must perform to accomplish the functions that are allocated to HAs. TA also identifies the alarms, information, controls, and task support that must be available for plant personnel to successfully perform these tasks. TA generates input to several program elements: staffing and qualifications, HSI design, procedure development, training program development, and V&V. The NRC staff's objective in the review of this element is to verify that the TA will be adequate to address these needs. The NRC staff evaluated the HFEPP using the relevant review criteria in NUREG-0711, section 5.4, "Review Criteria," and the results of the NRC staff's evaluation are discussed below in sections 4.1 through 4.4. The NRC staff notes that, per NUREG-0711, an associated RSR is expected for this element, however, RSRs are not included as part of this HFEPP and will need to be submitted and reviewed as part of an OLA.

4.1 Scope (Criterion 5.4(1))

Criterion 5.4(1) lists tasks that should be part of the scope of the applicant's TA, including (1) all important HAs (determined by probabilistic and deterministic means), (2) tasks that represent the full range of plant operating modes, and (3) eight specific types of tasks listed in criterion 5.4(1) (e.g., tasks that are new compared to those in predecessor plants). As discussed in section 3.1 of this evaluation, the FRA defines those functions linked to the plant's principal design requirements and yields the complete list of functions for input into the AOF process.

The AOF is described in the HFEPP as allocating those plant functions to humans, machines, or combinations thereof (e.g., shared human-machine operation or a human providing backup to a machine) via an iterative process. Section 5.6, "Task Analysis," of the TR states that the TA identifies task requirements to accomplish those functions that are allocated to humans (including any partial allocations made to humans).

Appendix B of the TR describes the methodology used in systematically conducting the TA. In section B.1.2, "Scope," the TA process is stated to address human interactions with NI plant systems. Section B.2.1.1, "System Design Inputs," discusses that system design inputs to include, in part, **[[ ]]**, relevant OE, and those tasks allocated during the AOF process. Section B.2.1.2, "Plant Information," further explains that the TA process also incorporates narratives that describe how the plant functions through its modes of operation and an HFE concept of operations (COO), in addition to both **[[ ]]**

The NRC staff notes that the described scope of the HFEPP TA is not as specific as that that described by criterion 5.4(1) and that the plan instead presents a more generalized methodology that reflects a "top-down" approach to identifying tasks. The HFEPP discusses certain aspects of criterion 5.4(1), such as the inclusion of HAs that were identified by deterministic means, the consideration of functions throughout various modes of plant operation, and backup functions in the event of automation (i.e., machine allocated task) failures. However, not all aspects of the specific types of tasks described by the criterion 5.4(1) are explicitly addressed. The NRC staff notes that the described FRA and AOF processes that input into the TA (i.e., a top-down HFE approach) should reasonably result in a TA scope that is consistent with the underlying objective of criterion 5.4(1). Furthermore, the NRC staff notes that since the TA process discussed in the HFEPP only reflects the IP stage, the TA RSR, when completed, will provide the NRC staff an opportunity to confirm the adequacy of the completed TA process scope.

As previously discussed in the evaluation of the HFE program management element of the HFEPP, section 1.2 of the TR describes that control and monitoring of both NI and EI equipment is performed from HSIs in the MCR, with the layout and interface of both NI and EI workstations being of the same general design within an integrated overall MCR design. However, TerraPower states that the EI itself is not included within the scope of the HFEPP, with the justification being that no EI SSCs "…are required to (1) respond to mitigate any events impacting the NI, (2) support safety-related, SSCs, or (3) endure defense-in-depth adequacy." The NRC staff previously evaluated key implications of the separation of the NI and EI portions of the Natrium design, as documented under, "Final Safety Evaluation of Topical Report NATD-LICRPRT-0001, 'Regulatory Management of Natrium Nuclear Island and Energy Island Design Interfaces'" and note that TerraPower's characterization of the significance of EI operations to NI safety is consistent with prior staff conclusions. Based upon that, the NRC staff determined that exclusion of the EI from the scope of the TA and HSI design elements is reasonable because human performance within that location is not reasonably expected to influence Natrium safety outcomes in an appreciable manner. The NRC staff has determined that TerraPower's plan for TA has an adequate scope and, therefore, concludes that criterion 5.4(1) is met.

4.2 <u>Screening Methodology (Criterion 5.4(2))</u>

Criterion 5.4(2) states that the applicant should describe the screening methodology used to select the tasks for analysis, based on criteria specifically established to determine whether analyzing a particular task is necessary. **[[**

]]

Section 3.2 of the TR discusses that **[[**

]]

Based on the above, the NRC staff has determined that TerraPower's plan for TA includes a screening methodology for selecting tasks for analysis and, therefore, concludes that criterion 5.4(2) is met.

4.3 Task Attributes and Iterative Process (Criteria 5.4(3) – (8))

NUREG-0711, Criteria 5.4(3) – (7), state that the applicant should (3) begin TA with detailed narratives of what personnel have to do, along with specifying the alarms, information, controls, and task support needed to accomplish the task, (4) identify the relationships among tasks, (5) estimate the time required to perform tasks, (6) identify the number of people required to perform each task, and (7) identify the knowledge and abilities required to perform each task. Criterion 5.4(8) states that the applicant's TA should be iterative and updated as the design is better defined.

Section 5.6 of the TR discusses that the TA identifies task requirements to accomplish plant functions that have been allocated to humans, with appendix B describing the methodology used in systematically conducting the TA. As noted by the staff in section 4.2 of this evaluation, **[[**

]]

Section 5.6 of the TR describes the following information as being documented, in part, for tasks associated with **[[** **]]**:

- Descriptive narrative of the task
- Time available versus time required to complete
- Action to be taken
- Information needed
- Controls needed
- Alarms needed
- Location and access considerations
- Workspace needed
- Job aids, tools, or equipment needs
- Environmental considerations and potential hazards
- Special or protective clothing needs

The NRC staff notes that the items above generally address the scope of considerations included under Criterion 5.4(3) for task narratives and Criterion 5.4(5) for time estimates.

Table B.2-1, "Task Step Sequence Narrative Definition Process," of the TR includes **[[**

]] Additionally, section C.4 of the TR describes that the TA process identifies all plant personnel involved to complete a task. Furthermore, section 5.9 of the TR discusses that tasks which support plant functions are identified as part of TA and that those tasks that are selected for training under the SAT are then analyzed to determine the required skills, knowledge, and abilities. Finally, section B.1.1, "Purpose," describes that the TA process as being "…repeated through the iterative design process and if needed for design modifications." The NRC staff has determined that this is generally consistent with the identification of the relationships among tasks, the identification of the number of people required to perform each task, the identification of the knowledge and abilities required to perform tasks, and the use of an iterative TA process as covered under criteria 5.4(4), 5.4(6), 5.4(7) and 5.4(8).

[[

]] The NRC staff has determined that TerraPower's plan for TA accounts for detailed narratives, task relationships, time estimates, numbers of people required, identification of knowledge and abilities, and iterations during the design process. Therefore, the NRC staff concludes that criteria 5.4(3) – (7) are met.

4.4 Reliability and Feasibility (Criterion 5.4(9))

NUREG-0711, criterion 5.4(9), states that the applicant should analyze the feasibility and reliability of important HAs and lists topics that should be considered in doing so.

Table A.2-1, "Initial Allocation of Function Definition Steps," of the TR addresses initial allocations of functions to humans. This table includes feasibility considerations for human agents that consist of the following: ability to detect, response time limits, reliability of response, acceptable cognitive workload, and acceptable physical workload. As discussed in section 4.1 of this evaluation, the output of the AOF process serves as the input into the TA. Section 5.5 of the TR states that that "HAs important to safety are determined using both deterministic and probabilistic means from the safety analysis and PRA," as well as that "HRA is conducted by the risk and reliability team and is an integral part of the development of a complete PRA." Section D.1.1, "Purpose," of the TR states that the HFE V&V process includes the sampling of tasks that are of greatest risk-significance, with those tasks then being verified and validated. The NRC staff has determined that TerraPower's plan for TA, as considered within the context of the broader HFEPP, includes analysis of the feasibility and reliability of important HAs and, therefore, concludes that criterion 5.4(9) is met.

4.5 Overall Conclusion for the Task Analysis Element

The NRC staff concludes that TerraPower's plan for TA, as described by the TR, is generally consistent with the relevant criteria of NUREG-0711. The associated results of this plan's implementation can be reviewed by the NRC staff when a future TA RSR is provided.

5.0 STAFFING AND QUALIFICATIONS

The NRC staff's objective in the review of this element is to verify that the applicant will systematically analyze the number and necessary qualifications of personnel in concert with task requirements and regulatory requirements. The NRC staff evaluated the HFEPP using the relevant review criteria in NUREG-0711, section 6.4, "Review Criteria," and the results of the NRC staff's evaluation are discussed below in sections 5.1 through 5.6. It should be noted that, per NUREG-0711, an associated RSR is expected for this element, however, RSRs are not included as part of this HFEPP and will need to be submitted and reviewed as part of an OLA.

5.1 Staffing and Qualifications Guidance Conformance (Criterion 6.4(1))

NUREG-0711, criterion 6.4(1), states that the applicant should address the applicable staffing and qualifications guidance in NUREG-0800, section 13.1. However, the information to be reviewed under NUREG-0800, sections 13.1.1, "Management and Technical Support Organization," [20] and 13.1.2 – 13.1.3, "Operating Organization," [21] is not expected to be completely available until an OLA is submitted[6]. Thus, no review equivalent to that of NUREG-0800, chapter 13.1, was conducted during this evaluation of the HFEPP under NUREG-0711, section 6, "Staffing and Qualifications." This represents an incomplete aspect of the NUREG-0711 review methodology that is addressed in the "Limitations and Conditions" section of this evaluation.

5.2 Staffing and Qualifications Regulatory Compliance (Criterion 6.4(2))

Criterion 6.4(2) states that the applicant should address the applicable staffing and qualifications requirements of 10 CFR 50.54, "Conditions of licenses." Section 6.5 of the TR states that RSRs will be developed addressing at least the minimum information stipulated in NUREG-0711 and that TerraPower will provide the RSRs for NRC staff review. The NRC staff notes that, per NUREG-0711, an associated RSR is expected for the staffing and qualifications element.

[6] NUREG-0800, sections 13.1.1 and 13.1.2 – 13.1.3, are referenced by the guidance and related criteria of DANU-ISG-2022-05.

During the audit, TerraPower clarified that the requirements of 50.54(k) through (m) will be addressed by the OLA and, furthermore, that TerraPower will seek an exemption via the OLA for the omission of the STA role. Based on the above, the NRC staff has determined that evaluation of how TerraPower will address the applicable staffing and qualifications requirements of 10 CFR 50.54 can reasonably be deferred until the review of the OLA and in conjunction with the related RSR, when it becomes available. Furthermore, the treatment of the STA role by users of this TR is addressed in the “Limitations and Conditions” section of this evaluation.

5.3 Inputs from TA to Staffing and Qualifications Analyses (Criterion 6.4(3))

Criterion 6.4(3) states that the applicant should use the results of the TA as input to the staffing and qualifications analyses. It also states that personnel tasks should be assigned to staffing positions to ensure that jobs are defined considering task characteristics, team processes, and the person’s ability to maintain situational awareness. Section C.3, “Staffing Analysis Overview,” of the TR describes that the major steps of staffing analysis include the TA process, during which both the definition of task steps and personnel assignments occur. The TA is stated as forming the basis for the qualifications associated with each personnel role. An expert panel reviews TA data (which includes timeline analysis for the most resource-intensive credible events) to evaluate the adequacy of staffing as it relates to responding to events. Testing is then used to evaluate workload and factors such as situational awareness, with the results being used to inform changes in staffing and/or job design. The NRC staff has determined that TerraPower’s plan for analyzing staffing and qualifications considers inputs from the TA and, therefore, concludes that criterion 6.4(3) is met.

5.4 Staffing for the Full Range of Plant Conditions and Tasks (Criterion 6.4(4))

Criterion 6.4(4) states that the applicant’s staffing analysis should determine the number and qualifications of operations personnel for the full range of plant conditions and tasks (including operational tasks conducted under normal, abnormal, and emergency conditions; plant maintenance; plant surveillance; and testing) and should address how plant personnel working outside of the control room interface with the operators in the control room.

Section 5.4 of the TR discusses that the staffing analysis determines the minimum required staff complement. The analysis is described as beginning with staffing and shift-work assumptions from the COO as a baseline. Section 5.4 of the TR states that “[t]he 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 NRC staff notes that, while not specifically addressed under the staffing and qualification element of the HFEPP, appendix D of the TR incorporates communications and coordination between field operators and the control room into validation testing processes. The NRC staff has determined that TerraPower’s plan for analyzing staffing and qualifications addresses staffing across the full range of plant conditions and tasks and, therefore, concludes that criterion 6.4(4) is met.

5.5 Iteration (Criterion 6.4(5))

Criterion 6.4(5) states that the applicant’s staffing analysis should be iterative; that is, the initial staffing goals should be modified as information from the HFE analyses of other elements becomes available. Section 5.4 of the TR describes that the staffing analysis begins with staffing assumptions from the COO and that this baseline staffing is either validated, or corrected, as it is subsequently used to analyze the most resource-intensive events across various operating states. Staffing levels are updated as warranted based upon the completion of further staffing analysis activities, including workload analysis and evaluations (using means such as mock-ups, modeling, or simulation) with ISV providing the final validation for staffing. The NRC staff has determined that TerraPower's plan for analyzing staffing and qualifications provides for an iterative process and, therefore, concludes that criterion 6.4(5) is met.

5.6 Staffing-related Issues (Criterion 6.4(6))

Criterion 6.4(6) states that the applicant should address the basis for staffing and qualifications levels and lists topics to be considered. The topics are associated with the following HFE elements: OER, FRA/FA, TA, treatment of important human actions (TIHA), procedure development, and training program development. Section C.4 of the TR discusses that the staffing analysis uses, in part, inputs from the OER, AOF, and TA. **[[**

]] Section C.3 of the TR describes that the staffing analysis includes consideration of the most resource-intensive credible events to evaluate the adequacy of staffing.

Section 5.8 of the TR describes that the procedures developed by the associated element of the HFEPP are used for ISV. In a similar manner, section 5.9 of the TR states that the participants used for ISV will be trained using the training program developed under that element of the HFEPP to validate the integrated design. Section 5.4 discusses that staffing levels are updated as warranted based upon the completion of staffing analysis activities, with ISV serving as the final validation stage for staffing. The NRC staff notes that, while the HFEPP does not explicitly discuss each of the specific considerations listed under criterion 6.4(6), the processes and methodologies that the HFEPP describes as iteratively informing staffing, and qualifications should reasonably achieve the underlying objective of the criterion. Based on the above, the NRC staff has determined that TerraPower's plan for analyzing staffing and qualifications addresses staffing-related issues and, therefore, concludes that criterion 6.4(6) is met.

5.7 Overall Conclusion for the Staffing and Qualifications Element

The NRC staff concludes that, subject to the limitations and conditions contained in this evaluation, TerraPower's plan for staffing and qualifications, as described by the TR, is generally consistent with the relevant criteria of NUREG-0711. The associated results of this plan's implementation can be reviewed by the NRC staff when a future staffing and qualifications RSR has been provided.

6.0 TREATMENT OF IMPORTANT HUMAN ACTIONS

The TIHA program element identifies the HAs that are most important to safety and considers those HAs in the HFE design of the plant. The design should minimize the likelihood of personnel error and help ensure that personnel can detect and recover from any errors that occur. The NRC staff's objective in the review of this element is to verify the adequacy of the TIHA program. The NRC staff evaluated the HFEPP using the relevant review criteria in NUREG-0711, section 7.4, "Review Criteria," and the results of the NRC staff's evaluation are discussed below in sections 6.1 through 6.2. The NRC staff notes that, per NUREG-0711, an associated RSR is expected for this element, however, RSRs are not included as part of this HFEPP and will need to be submitted and reviewed as part of an OLA.

6.1 Identification of Important Human Actions (Criteria 7.4(1) – (2))

Criterion 7.4(1) states that the applicant should identify risk-important HAs from the PRA and HRA. Criterion 7.4(2) states that the applicant should identify deterministically important HAs from those actions credited in accident and transient analyses, as well as those identified during any I&C-related diversity and defense-in-depth (D3) coping analyses.

Section 3 of the TR states that **[[**

]] Additionally, as discussed under section 3.1 of this evaluation, the AOF is described in the HFEPP as allocating functions to humans, including allocations in which a human agent provides backup to a machine agent. The allocations made during the AOF process, in turn, inform the TA. The NRC staff notes that, while D3 is not specifically addressed in the HFEPP, the identification of where human backup roles exist, as well as their relative safety significance, is consistent with the expected role of an HFE program within the broader D3 analysis and appropriate for the earlier stages (e.g., pre-OLA) of the design process. The NRC staff has determined that TerraPower's plan for the treatment of important HAs addresses the identification of important HAs and, therefore, concludes that criteria 7.4(1) – (2) are met.

6.2 Treatment of Important Human Actions in the Human Factors Engineering Process (Criterion 7.4(3))

Criterion 7.4.3(3) states that the applicant should specify how important HAs are addressed by the HFE program in FA, TA, HSI design, procedural development, and training program development to minimize the likelihood of human error and facilitate error detection and recovery capability.

As discussed within section 4.4 of this evaluation, the HFEPP describes the AOF process as considering feasibility and reliability when making initial allocation of functions to human agents, with the output of the AOF process serving as the input into the TA. As discussed in section 6.1 of this evaluation, **[[**

]].

Furthermore, section 5.9 of the TR discusses that tasks which support plant functions are identified as part of TA and then selected for training according to a SAT-based training approach. Under this approach, tasks are described as being selected for training based upon a difficulty, importance, and frequency ranking process that is described as being the training equivalent to the graded approach that is taken to HAs under section 3 of the TR. **[[**

]] Based on the above, the NRC staff has determined that TerraPower's plan for the treatment of important HAs addresses important HAs in the HFE process and, therefore, concludes that criterion 7.4.3(3) is met.

6.3 Overall Conclusion for the TIHA Element

The NRC staff concludes that TerraPower's plan for TIHA, as described in the TR, is generally consistent with the relevant criteria of NUREG-0711. The associated results of this plan's implementation can be reviewed by the NRC staff when a future TIHA RSR has been provided.

7.0 HUMAN-SYSTEM INTERFACE DESIGN

The HSI design element represents the translation of function and task requirements into HSI design specifications. The objective of this review is to evaluate how HSI designs are identified and refined. The review verifies that the applicant has a process to translate functional and task requirements to the detailed design of alarms, displays, controls, and other aspects of the HSI through the systematic application of HFE principles and criteria. The NRC staff's objective in the review of this element is to verify the adequacy of the HSI design approach. The NRC staff evaluated the HFEPP using the relevant review criteria in NUREG-0711, section 8.4, "Review Criteria," and the results of the NRC staff's evaluation are discussed below in sections 7.1 through 7.6. It should be noted that, per NUREG-0711, an associated RSR is expected for this element, however, RSRs are not included as part of this HFEPP and will need to be submitted and reviewed as part of an OLA.

7.1 Human-System Interface Design Inputs (Criteria 8.4.1(1) – (4))

NUREG-0711, criterion 8.4.1(1), lists analyses and inputs that the applicant should use early in the design process to identify requirements for HSI design, including operational experience, FRA/FA, TA, and staffing and qualifications analysis. Criteria 8.4.1(2) – (4) state that the applicant should identify constraints on HSI design from system requirements, regulatory requirements, and other sources, such as customer requirements, as inputs to the HSI design. The NRC staff considered whether analyses conducted in earlier states of the HFEPP are utilized to identify HSI requirements. Section B.2.2.5.5 of the TR describes **[[**

]] Section B.2.2, "Task Analysis Process," of the TR describes that the output of the AOF process serves as the starting input for the TA. Section B.3, "Human-System Interface Design Methodology," of the TR states the output of the TA informs the design of the HSIs. Appendix B discusses points in the HSI design process during which staffing-related inputs are considered.

The NRC staff also considered whether constraints on HSI design were identified. Section B.2.1, "Task Analysis Inputs," of the TR describes inputs from the TA process that inform HSI development. **[[**

]] Section B.3.1.2, "Human-System Interface Design Requirements Input," of the TR further describes that a main input to the HSI design includes, in part, HFE regulations and standards. The NRC staff has determined that TerraPower's plan for HSI design addresses the use of early results in the design process to identify requirements for

HSI design, as well as design constraints, and, therefore, concludes that criterion 8.4.1(1) is met.

7.2 Concept of Use and HSI Design Overview (Criteria 8.4.2(1) – (2))

7.2.1 Concept of Use (Criterion 8.4.2(1))

Criterion 8.4.2(1) states that the applicant should develop a concept of use stating the roles and responsibilities of operations personnel based upon anticipated staffing levels. Section 5.7.2, “Human Factors Engineering Concept of Operation,” of the TR states that the HFE COO document serves the role of a concept of use. The HFE COO document is described as providing information on how users interact with HSIs and with each other to operate the plant. The HFE COO is also described as providing assumptions regarding user roles and minimum staffing. The NRC staff has determined that TerraPower’s plan for HSI design addresses the development of an appropriate concept of use and, therefore, concludes that criterion 8.4.2(1) is met.

7.2.1 HSI Design Overview (Criterion 8.4.2(2))

Criterion 8.4.2(2) states that the applicant should provide an overview of the HSI, covering the technical bases and demonstrating that they constitute a state-of-the-art HSI design which supports personnel performance. Section 5.7.4 of the TR describes that the HSI design process includes the development and application of HFE design requirements (i.e., the HFE DRD) that include, in part, requirements for information displays, user interfaces, controls, alarms, safety parameter monitoring, computer-based procedures, workstations, and labeling. The HFE DRD and HFE design documents are described as being developed to comply with codes, standards, and HFE best practices (e.g., NUREG-0700). The results of HSI evaluations are described as being fed back into the HSI design using an HFE issue tracking process. The NRC staff has determined that TerraPower’s plan for HSI design addresses the incorporation of appropriate technical bases to inform a state-of-the-art HSI design and, therefore, concludes that criterion 8.4.2(2) is met.

7.3 Human Factors Engineering Design Guidance for Human-System Interfaces (Criteria 8.4.3(1) – (5))

NUREG-0711, section 8.4.3, “HFE Design Guidance for HSIs,” includes five criteria that the NRC staff used to address design-specific HFE design guidance that an applicant should develop and use for HSI features, layout, and environment. NUREG-0711 refers to this type of design guidance as a “style guide.” For HSI design, the style guide should do the following:

- Address the scope of HSIs and their form, function, operation, and environmental conditions that are relevant to human performance (Criterion 8.4.3(1)).
- Contain guidance derived from generic HFE guidance and HSI design-related analyses and reflect the applicant’s decisions in addressing specific goals of the HSI design (Criterion 8.4.3(2)).
- Contain precisely expressed individual guidelines and observable HSI characteristics and details for design personnel to use for the purpose of design consistency and verifiability (Criterion 8.4.3(3)).

- Contain procedures, supplemented with graphical examples, figures, and tables to facilitate comprehension, for determining where and how HFE guidance will be used in the overall design process (Criterion 8.4.3(4)).
- Be readily accessible and usable by designers, with references to source documents included, and be updated as the design matures (Criterion 8.4.3(5)).

Section 5.7.4 of the TR states that “the scope of a ‘Style Guide’ is covered within the HFE DRD and the HSI Style Specification.” The HFE DRD and HFE design documents are described as being developed to comply with codes, standards, and HFE best practices (e.g., NUREG-0700). Section 5.7.4 of the TR states that the HFE design requirements are contained within a hierarchal document structure, with the HFE DRD serving to contain the higher-level set of HFE design requirements for the project. The HSI style specification is described, in turn, as containing the implementation-level design requirements for both hardware-based panels and software-based displays, with bases for requirements being traceable back to the HFE DRD. Additionally, section 5.7.4 of the TR states that the HFE DRD and style specification requirements will be provided to suppliers for the NI HSIs though the procurement process, which supports consistency across the HSIs in the MCR, RSC, and LCSs. The NRC staff has determined that, while an HFE style guide is not yet available to be reviewed by the NRC staff in conjunction with the HFEPP, TerraPower’s plan for HSI design addresses the development of an HFE style guide and the evaluation of the completed style guide can reasonably be deferred until the review of an OLA in conjunction with the HSI Design RSR.

7.4 HSI Detailed Design and Integration (Criteria 8.4.4.1 – 8.4.4.6)

7.4.1 General HSI Design and Integration (Criteria 8.4.4.1(1) – (8))

7.4.1.1 HSI Design Supports IHAs (Criterion 8.4.4.1(1))

Criterion 8.4.4.1(1) states that for important HAs, the applicant’s design should minimize the probability that errors will occur and maximize the probability that any error made will be detected.

The NRC staff considered whether state-of-art HFE principles are applied in the HSI design process for important HAs to minimize human errors. Section 5.6 of the TR states that **[[**

]] Section B.3.2, “Human-System Interface Design Process,” describes that, **[[**

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The NRC staff notes that these activities help to minimize human errors and facilitate the ability of human errors to subsequently be detected and corrected. The NRC staff has determined that TerraPower’s plan for HSI design addresses minimization of human errors and, therefore, concludes that criterion 8.4.4.1(1) is met.

7.4.1.2 HSI Layout is Based on Job Analysis (Criterion 8.4.4.1(2))

Criterion 8.4.4.1(2) states the applicant should base the layout of HSIs within consoles, panels, and workstations on (1) analyses of personnel roles (job analysis) and (2) systematic strategies for organization, such as arrangement by importance, and frequency and sequence of use. Section B.2.2.5.3, "Job Design, Preliminary Workload Analysis, and Workplace Design and Layout Organization," of the TR describes **[[**

]] Table B.2-4, "Job Design, Preliminary Workload Analysis, and Workplace Design and Layout Organization Definition," of the TR provides **[[**

]] Table B.3-2, "User Interface Specification and Data Connection Table Creation Process," of the TR describes **[[**

]] The NRC staff has determined that TerraPower's plan for HSI layout design is based on job analysis and systematic strategies for organization and, therefore, concludes that criterion 8.4.4.1(2) is met.

7.4.1.3 HSI Design Supports Inspection, Maintenance, and Testing activities (Criterion 8.4.4.1(3))

Criterion 8.4.4.1(3) states that the applicant should design the HSIs to support inspection, maintenance, test, and repair of (1) plant equipment and (2) the HSIs.

The introduction section of the TR states that one of the HFE design goals is to ensure that working areas and their environments are designed for the human to perform, in part, maintenance, inspection, surveillance, and test activities. Section B.3 of the TR discusses the HSI design methodology and states that the user task types considered, include maintenance, test, surveillance, and inspection activities. Section B.3.2 of the TR describes **[[**

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Section B.6.1.4, "Workstation and Panel Configurations," of the TR presents **[[**

]] The NRC staff has determined that TerraPower's plan for HSI design addresses the support of inspection, maintenance, test, and repair activities and, therefore, concludes that criterion 8.4.4.1(3) is met.

7.4.1.4 HSI Design Supports Task Performance Under Conditions of Minimal, Typical, and Maximum Staffing (Criterion 8.4.4.1(4))

Criterion 8.4.4.1(4) states that the applicant's design should support personnel task performance under conditions of minimum-, typical-, and high-level or maximum staffing.

Section 5.7.2 of the TR describes development of the HFE COO document which, in part, includes job design aspects such as the definition of user roles and minimum staffing. Section 5.10 of the TR describes HFE ISV that evaluates the performance of the integrated HSI design with respect to other HFE elements such as plant personnel roles, staffing and qualifications, and task assignments. ISV evaluates the performance of the integrated HSI design in terms of, in part, personnel tasks, crew coordination, situation awareness, and workload. Section B.4 of the TR describes **[[**

]] Additionally, section C.5.3, "Staffing Analysis in the Human Factors Engineering Verification and Validation Process," of the TR discusses validation of nominal shift levels, minimal shift levels, and shift turnover. The NRC staff notes that the overall HSI design testing and evaluation, ISV, and iterative HFE design processes together are consistent with the development of an HSI design that will support personnel task performance under various staffing conditions. The NRC staff has determined that TerraPower's plan for HSI tests and evaluation, as well as ISV, address HSI support for staffing conditions and, therefore, concludes that criterion 8.4.4.1(4) is met.

7.4.1.5 HSI Design Process Accounts for Fatigue (Criterion 8.4.4.1(5))

Criterion 8.4.4.1(5) states that the applicant's design process should account for using the HSIs over the duration of a shift where decrements in human performance due to fatigue may be a concern.

Section 5.10 of the TR describes that HF ISV tests participants performing a set of simulated challenging scenarios and demonstrates that the integrated HSI supports safe operation of the plant, including acceptable shift staffing and workload. Section B.2 of the TR describes **[[**

]] Appendix C of the TR describes that both workload and situational awareness are considerations that serve as inputs within the staffing analyses. Section D.4 of the TR discusses **[[**

]] Additionally, section D.4.3, "Representative Population Sampling," describes that the sampling of conditions during ISV should include, in part, circadian factors (i.e., with a subset of scenarios run during night-shift). These design considerations serve, in aggregate, to address fatigue among shift personnel. The NRC staff has determined that TerraPower's plan for HSI design, staffing, and ISV account for personnel fatigue and, therefore, concludes that criterion 8.4.4.1(5) is met.

7.4.1.6 HSI Characteristics Support Human Performance Under a Full Range of Environmental Conditions (Criterion 8.4.4.1(6))

Criterion 8.4.4.1(6) states that the characteristics of the applicant's HSIs should support human performance under the full range of environmental conditions, ranging from normal to credible extreme conditions, such as loss of lighting and of ventilation. The NRC staff evaluated how the range of environmental conditions are considered in the HSI design process. Section B.2 of the TR describes the TA process that provides input for HSI design, with Section B.2.2.5.3 discussing **[[**

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In addition, section D.4.3 of the TR describes that ISV sampling considerations should include environmental factors such as poor lighting and high noise. Section D.5.5.2, "Human Factors Engineering Design Verification Evaluation Methods," of the TR specifically discusses the HFE evaluation of environmental aspects (e.g., lighting, noise, temperature, ventilation). This section notes that some of these aspects may be verified using a full-scope simulator, but others must instead be verified under the design implementation element after the plant has been constructed. The NRC staff has determined that TerraPower's plans for TA, HSI design, and V&V, in aggregate, address HSI support for human performance under the range of environmental conditions and, therefore, conclude that criterion 8.4.4.1(6) is met.

7.4.1.7 The Applicant has a Change Process for HSIs in the Operating Plant (Criterion 8.4.4.1(7))

Criterion 8.4.4.1(7) states that the applicant should identify how, in an operating plant, the HSIs are modified and updated, temporary HSI changes are made, and personnel-defined HSIs are created. During the audit, TerraPower clarified that, once the plant is turned over to the licensee, any modification or updates to the HSIs will be in accordance with the administrative procedures described in the PSAR. The NRC staff has determined that review of TerraPower's process for how HSI design modifications and changes will be addressed during the operating phase can reasonably be deferred until review of the OLA.

7.4.2 Main Control Room (Criteria 8.4.4.2(1) – (15))

The NRC staff reviewed the HFEPP to determine how the HFEPP addresses the criteria outlined in NUREG-0711, section 8.4.4.2, "Main Control Room," which includes the requirements in 10 CFR 50.34(f)(2) related to lessons learned from the accident at the TMI reactors. The NRC staff did not evaluate criterion 8.4.4.2(4) (applicable to pressurized-water reactors only) nor did the NRC staff evaluate criteria 8.4.4.2(8) – (9), (applicable to boiling-water reactors only) because Natrium is a non-light water reactor design.

7.4.2.1 Post-TMI HSI Inventory Requirements (Criteria 8.4.4.2(1-3), (5-7), and (10–11))

- Criterion 8.4.4.2(1) addresses 10 CFR 50.34(f)(2)(iv) that discusses the safety parameter display system (SPDS). Criterion 8.4.4.2(1) states that the applicant should describe the safety parameter display system, addressing the identification of critical safety functions, identification of the parameters personnel will use to monitor each critical safety function, and evaluation of SPDS HSIs.
- Criterion 8.4.4.2(2) addresses 10 CFR 50.34(f)(2)(v) that discusses the bypassed and inoperable status indication Criterion 8.4.4.2(2) states that the applicant should describe how the HSI assures the automatic indication of the bypassed and inoperable status of a safety function, and the systems actuated or controlled by the safety function.
- Criterion 8.4.4.2(3) addresses 10 CFR 50.34(f)(2)(xi) that discusses relief and safety valve indication. Criterion 8.4.4.2(3) states that the applicant should describe how the HSI indicates the position of the relief and safety valves (open or closed) in the control room.
- Criterion 8.4.4.2(5) addresses 10 CFR 50.34(f)(2)(xvii) that discusses containment monitoring. Criterion 8.4.4.2(5) states that the applicant should describe how the control room's HSIs (alarms and displays) inform personnel about, in part, containment radiation intensity and noble gas effluents for potential, accident release points.
- Criterion 8.4.4.2(6) addresses 10 CFR 50.34(f)(2)(xviii) that discusses core cooling. Criterion 8.4.4.2(6) states that the applicant should describe how the HSI provides unambiguous indication of inadequate core cooling.
- Criterion 8.4.4.2(7) addresses 10 CFR 50.34(f)(2)(xix) that discusses post-accident monitoring. Criterion 8.4.4.2(7) states that the applicant should describe how the HSI

assures monitoring of plant and environmental conditions following an accident including core damage.

- Criterion 8.4.4.2(10) addresses 10 CFR 50.34(f)(2)(xxvi) that discusses leakage control. Criterion 8.4.4.2(10) states that the applicant should describe how the HSI provides for leakage control and detection in the design of systems outside containment that contain (or might contain) accident-source-term radioactive materials after an accident.
- Criterion 8.4.4.2(11) addresses 10 CFR 50.34(f)(2)(xxvii) that discusses radiation monitoring. Criterion 8.4.4.2(11) states that the applicant should describe how the HSI provides appropriate monitoring of in-plant radiation and airborne radioactivity under a broad range of routine and accident conditions.

These HSI elements are linked to regulatory requirements associated with the lessons learned from the accident at TMI and, as technologically relevant, are expected to be considered within the HSI inventory as part of the HFE design process. Thus, the NRC staff evaluated whether the HFEPP establishes how these items will be addressed within the HSI design and validation processes.

Section 5.7 of the TR describes a systematic process of HSI design, including TA, defining HSI concepts, defining key parameters to be displayed or controlled, and performing test and evaluation. It is stated that the HFE DRD includes requirements, in part, for information displays, as well as for the safety function and parameter monitoring system. Section B.2 describes TA processes that provide the input for HSI design. Table B.2-5, “Human-System Interface Key Parameters Definition,” describes **[[**

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Additionally, section 5.7.5, “Detailed Human-System Interface Design,” of the TR states that HSI design specifications will be provided to the vendor in the form of a user interface specification. Finally, it is also stated in this section that “the final MCR design will provide indications that meet the technologically relevant aspects of 10 CFR 50.34… paragraphs (f)(2)(iv), (v), (xi), (xvii), (xviii), (xix), (xxvi), and (xxvii).”

The NRC staff has determined that TerraPower’s plan for HSI design will address the incorporation of technologically relevant, post-TMI HSI inventory requirements and, therefore, concludes that criteria 8.4.4.2(1-3), (5-7), and (10–11) are met.

7.4.2.9 Manual Initiation of Protective Actions (Criterion 8.4.4.2(12)) and Diversity and Defense-In-Depth (Criterion 8.4.4.2(13))

Criterion 8.4.4.2(12) states that the applicant should describe how the HSI supports the manual initiation of protective actions at the system level for safety systems otherwise initiated automatically. Criterion 8.4.4.2(13) states that the applicant should describe how the HSI provides displays and controls in the control room for manual, system-level actuation of critical safety functions, and for monitoring those parameters that support them. These displays and controls should be independent of, and different from, the normal I&C.

Section 5.2 of the TR describes that a defense-in-depth methodology is included within the FRA process which establishes functions with sufficient independence (including any needed control and instrumentation diversity) to assure adequate safety should failures or degradations occur. Additionally, section 5.2 of the TR states that certain defense line functions are specified as manual HAs, with the appropriateness of those manual HAs being confirmed by means of the AOF process. Section D.6.7, "Human Factors Engineering Validation Performance Measures," of the TR describes performance measures that are used during HFE ISV. **[[**

]] Section D.6.7.1, "Plant - Core Thermal-Hydraulic Condition," of the TR discusses **[[**

]] During the audit, TerraPower clarified how defense-in-depth functions are classified, as well as that no safety-related manual actions are expected.

Based on the above, the NRC staff has determined that TerraPower's plan for HSI design addresses the manual initiation of protective actions for safety systems, as well as providing diverse and independent displays and controls for manual actuation and monitoring of critical safety functions. Therefore, the NRC staff concludes that criteria 8.4.4.2(12) – (13) are met.

7.4.2.10 Important Human Actions (Criterion 8.4.4.2(14))

Criterion 8.4.4.2(14) states that the applicant should describe how the HSI provides the controls, displays, and alarms that ensure the reliable performance of identified important HAs. The NRC staff evaluated whether the HFEPP describes a process identifying important HAs, translating the associated requirements to HSI design, and testing and evaluating the design.

Section 5.7 of the TR describes a systematic process of HSI design, including TA, defining HSI concepts, defining key parameters to be displayed or controlled, designing HSI, and performing test and evaluation. Section 6 of this evaluation previously addressed the TIHA HFE element. As noted in section 6 of this evaluation, **[[**

]] Section 5.7.7, "Graded Application of Human Factors During Human-System Interface Design," of the TR describes **[[**

]] Additionally, Section B.3.2 of the TR describes **[[**

]]

The NRC staff has determined that TerraPower's plan for HSI design addresses HSI support for important HAs and that the associated results of this plan's implementation can be reviewed by the NRC staff when an associated HSI design RSR is provided. Accordingly, the NRC staff concludes that the HFEPP meets Criterion 8.4.4.2(14).

7.4.2.11 Computer-based Procedures Platform (Criterion 8.4.4.2(15))

Criterion 8.4.4.2(15) states that the applicant's computer-based procedures should be consistent with the design review guidance in NUREG-0700, section 8, "Computer-Based Procedure System," and in section 1 of DI&C-ISG-5.[7]

Section 5.7.2 of the TR states that the HFE COO document contains the concept for computer-based procedures and includes references to standards such as IEEE 1786-2022, "IEEE Guide for Human Factors Applications of Computerized Operating Procedure Systems (COPS) at Nuclear Power Generating Stations and Other Nuclear Facilities" [22]. The NRC staff notes that the IEEE 1786-2022 standard addresses HFE considerations associated with computer-based procedures in a manner that would be expected to contribute to an adequate finalized design. Furthermore, section D.4 of the TR describes the methodology for sampling operational conditions during HFE V&V activities, with Section D.4.2, "Minimum Sample Conditions," describing **[[**

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The NRC staff has determined that TerraPower's plan for computer-based procedures addresses appropriate design review guidance and, therefore, concludes that criterion 8.4.4.2(15) is met.

7.4.3 Technical Support Center (Criteria 8.4.4.3(1) – (7)) and Emergency Operations Facility (Criteria 8.4.4.4(1) – (10))

NUREG-0696, "Functional Criteria for Emergency Response Facilities," [23] states that HFE should be incorporated in the design of the on-site TSC and EOF, with consideration of both operating and maintenance personnel. Although the specific emergency facilities associated with Natrium will be established in the emergency plan in conjunction with an OLA, the NRC staff notes that the criteria of NUREG-0711, section 8.4.4.3, "Technical Support Center," and section 8.4.4.4, "Emergency Operations Facility," describe principles that are broadly relevant to the HFE review of emergency facilities in general. Specifically, this includes the general HFE scope covered by criteria 8.4.4.3(1) through 8.4.4.3(7) and criteria 8.4.4.4(1) through 8.4.4.4(10).

Section 1.2 of the TR describes the scope of the Natrium HFE program and states, in part, that the HFEPP applies to NI-related HSIs in the emergency support facilities. Based upon this scope of HFE program applicability, the NRC staff notes that the HSI design processes described in section 5.7 and appendix B of the TR would be applicable to emergency facilities. Section 5.7 of the TR describes a systematic process of HSI design, including TA, defining HSI concepts, defining key parameters to be displayed or controlled, designing HSI, and performing test and evaluation. Section B.2 of the TR describes the TA methodology process which provides inputs for HSI design. Section B.2.1.2 of the TR describes **[[**

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Additionally, section B.3 of the TR establishes that a primary goal for HSI design is to facilitate efficient and reliable user performance during both emergency and accident plant conditions. The NRC staff notes that these programmatic attributes generally support the HSI design within emergency facilities.

The NRC staff has determined that, while the HFEPP establishes that TerraPower intends to apply HFE with the context of the Natrium emergency facilities, the specific details regarding both the nature of those emergency facilities and how HFE will be applied to them is not

[7] This ISG guidance was incorporated into NUREG-0800, chapter 18, revision 3 (ML16125A114).

expected to be available until an OLA has been submitted with an associated emergency plan. This represents an incomplete aspect of the NUREG-0711 review methodology that is addressed in the "Limitations and Conditions" section of this evaluation.

7.4.4 Remote Shutdown Facility (Criteria 8.4.4.5(1) – (2))

7.4.4.1 Description of Remote Shutdown Capability (Criterion 8.4.4.5(1))

Criterion 8.4.4.5(1) states that the applicant should describe how the HSI provides a design capability for remote shutdown of the reactor outside the MCR. Section 1.2 of the TR describes the scope of the program and states, in part, that the HFEPP applies to NI-related HSIs in the RSC. Based upon this scope of HFE program applicability, the NRC staff notes that the HSI design processes described in section 5.7 and appendix B of the TR would be applicable to the RSC. This entails a systematic process of HSI design, including TA, defining HSI concepts, defining key parameters to be displayed or controlled, and performing test and evaluation. Additionally, section D.1.2, "Scope," of the TR states that the HFE V&V process applies to the HSIs at the RSC. The NRC staff has determined that TerraPower's plan for HSI design addresses the capability for remote shutdown of the reactor outside the MCR and, therefore, concludes that criterion 8.4.4.5(1) is met.

7.4.4.2 Consistency of Remote Shutdown HSIs (Criterion 8.4.4.5(2))

Criterion 8.4.4.5(2) states that the applicant should describe how the HSIs at the remote shutdown facility are consistent with those in the MCR. Section 5.7.4 of the TR states that the HFE DRD and style specification requirements are provided to suppliers for the NI HSIs though the procurement process, which supports consistency across the HSIs in the MCR, RSC, and LCSs. Section 5.7.4 of the TR also states that the V&V process serves as a method to confirm the implementation of HFE requirements by suppliers. The NRC staff has determined that TerraPower's plan for HSI design addresses consistency between the HSIs located in both the MCR and RSC and, therefore, concludes that criterion 8.4.4.5(2) is met.

7.4.5 Local Control Station Design (Criteria 8.4.4.6(1) – (2))

7.4.5.1 Basis for Determining Local Control HSIs (Criterion 8.4.4.6(1))

Criterion 8.4.4.6(1) states that the applicant should describe the basis for deciding which HSIs will be included in the MCR design, and which will be provided locally.

Table B.2-4 of the TR presents **[[**

]]

Section D.6.3.1.3, "Testbed Verification," describes that risk-significant local field interfaces (including associated HSIs) are verified in accordance with the TSV and HFE design verification processes, which incorporate the validation of risk-significant local control operations. The NRC staff has determined that TerraPower's plan for HSI design addresses processes for determining where HSIs will be located and, therefore, concludes that criterion 8.4.4.6(1) is met.

7.4.5.2 Incorporation of HFE into local control station HSIs (Criterion 8.4.4.6(2))

Criterion 8.4.4.6(2) states that the applicant should describe how HFE was incorporated into the HSIs for LCSs to ensure they are consistent with those in the MCR, and that personnel easily understand and use the HSIs.

Section 1.2 of the TR describes the scope of the program and states, in part, that the HFEPP applies to NI-related HSIs for local controls. Based upon this scope of HFE program applicability, the NRC staff notes that the HSI design processes described in section 5.7 and appendix B of the TR would be applicable to such local controls. Section 5.7 of the TR describes a systematic process of HSI design, including TA, defining HSI concepts, defining key parameters to be displayed or controlled, and performing test and evaluation. Section 5.7.4 of the TR states that the HFE DRD and style specification requirements are provided to suppliers for the NI HSIs, which supports consistency across the HSIs in the MCR, RSC, and LCSs. Furthermore, section D.1.2 states that the HFE V&V process applies to the HSIs associated with NI local controls. The NRC staff has determined that TerraPower's plan for HSI design addresses the application of HFE to the HSIs of LCSs, as well as their consistency with those in the MCR, and, therefore, concludes that criterion 8.4.4.6(2) is met.

7.5 <u>Degraded Instrumentation and Controls and Human-System Interface Conditions (Criteria 8.4.5(1) – (4))</u>

Criteria 8.4.5(1) – (4) consider whether the applicant's HSI design approach adequately accounts for the identification of automation failures and degraded condition effects by operators, the timely detection of degraded I&C and HSI conditions by operators, the back-up systems needed to support personnel tasks under degraded I&C and HSI conditions, and the identification of required compensatory actions. Section 5.2 of the TR describes that a defense-in-depth methodology is included within the FRA process which establishes functions with sufficient independence (including any needed control and instrumentation diversity) to assure adequate safety should failures or degradations occur. Additionally, section 5.2 of the TR states that certain defense line functions are specified as manual HAs, with the appropriateness of those manual HAs being confirmed by means of the AOF process. Section 5.10 of the TR describes the overall HFE V&V process, which includes ISV that evaluates the performance of the integrated HSI design. Appendix D of the TR provides a detailed discussion of this V&V methodology, which incorporates considerations related to degraded I&C and HSIs.

Section D.4.2 of the TR describes **[[**

]] Additionally, section D.6.4.3, "Selecting and Documenting Events," of the TR discusses that the selection of events for ISV scenarios should include the degradation or failure of instruments, controls, and components. Section D.6.7 of the TR describes **[[**

]] Section D.6.7.1 of the TR discusses **[[**

]] Additionally, section D.9.1 of the TR, which describes **[[**

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During the audit, TerraPower confirmed that defense-in-depth functions involving non-safety-related with special treatment and no special treatment manual actions will be performed using diverse, independent HSI, as described in the PSAR (TerraPower indicated that no safety-related manual actions are expected at present).

The NRC staff has determined that TerraPower's plan for HSI design addresses the identification of automation failure and degraded condition effects, the timely detection of degraded I&C and HSI conditions, the needed backup systems to support personnel tasks under degraded I&C and HSI conditions, and identification of required compensatory actions. Therefore, the NRC staff concludes that criteria 8.4.5(1) – (4) are met.

7.6 HSI Tests and Evaluations (Criteria 8.4.6.1 – 8.4.6.2)

7.6.1 Trade-off Evaluations (Criteria 8.4.6.1(1) – (2))

7.6.1.1 Consideration of Human Performance (Criterion 8.4.6.1(1))

Criterion 8.4.6.1(1) states that in comparing design approaches, the applicant should consider those aspects of human performance important to performing tasks. This criterion describes certain factors that should be considered when selecting one design approach over another (e.g., personnel task requirements, HSI-system performance requirements, and human-performance capabilities and limitations). Section B.4.3.2, "Human Interface System Evaluation and User-Based Testing," of the TR discusses that the methods used during HSI evaluation methods include, in part, trade-off evaluations. Trade-off evaluations are described as being used for assessing design alternatives against one another or, alternatively, against an existing baseline. Section B.4.3.2.2 of the TR describes **[[**

]] The NRC staff has determined that TerraPower's plan for HSI design addresses appropriate factors to be considered during trade-off evaluations and, therefore, concludes that criterion 8.4.6.1(1) is met.

7.6.1.2 Relative Benefits of Design Alternatives (Criterion 8.4.6.1(2))

Criterion 8.4.6.1(2) states that the applicant should explicitly state the relative benefits of design alternatives and the basis for the design approach selected.

The NRC staff considered how the relative benefits of design alternatives are evaluated under the trade-off evaluation approach described in the HFEPP. Section B.4.3.2.2 of the TR describes that selected key criteria and the design alternatives are evaluated in a Pugh Matrix trade-off tool. Within the tool, importance ratings are assigned to criteria and evaluations against options (including a benchmark option) are made, with a numerical score being tabulated for alternatives. The scoring resulting from this process is used to make HSI design alternative trade-off decisions. The NRC staff has determined that TerraPower's plan for HSI design includes a structured and reasonable methodology for the selection of design alternatives and, therefore, concludes that criterion 8.4.6.1(2) is met.

7.6.2 Performance-based Tests (Criteria 8.4.6.2(1) – (3))

7.6.2.1 Objectives of Tests (Criterion 8.4.6.2(1))

Criterion 8.4.6.2(1) states that the applicant should identify the specific objectives of the tests. The NRC staff considered whether the specific objectives of performance-based tests are identified under the approach described in the HFEPP. Section B.4.3.2.3, "Performance-Based User Testing," of the TR establishes that the process of performance-based user testing begins with the preparation of a test plan that includes the purpose of the tests, as well as other aspects, such as the HSI design features to be tested and acceptance criteria to be used. The NRC staff has determined that TerraPower's plan for HSI design addresses establishing specific objectives for performance-based tests and, therefore, concludes that criterion 8.4.6.2(1) is met.

7.6.2.2 General Approach to Testing (Criterion 8.4.6.2(2))

Criterion 8.4.6.2(2) states that the applicant should base the general approach to testing on the test's objective(s).

This criterion describes certain aspects of tests that should be specified, including participants, testbed, HSI design features, tasks or scenarios used, performance measures, test procedures and data analyses. The NRC staff reviewed section B.4.3.2.3 of the TR, which describes test plan preparation, and notes that the described test plan elements are consistent with those of the criterion. Additionally, section B.4.3.2.3 provides further information regarding how to achieve each element such as, for example, selecting a testbed with consideration of the design features to be tested and by ensuring the population pool is sufficiently diverse and representative of the user population. The NRC staff has determined that TerraPower's plan for HSI design addresses the use of test objectives as a basis for performance-based testing and, therefore, concludes that criterion 8.4.6.2(2) is met.

7.6.2.3 Conclusions from the Tests (Criterion 8.4.6.2(3))

Criterion 8.4.6.2(3) states that the conclusions from the tests and their impact on design decisions should be described. The NRC staff considered how the processes described by the HFEPP serve to capture conclusions from performance-based testing, as well as the influence of those conclusions on design decisions.

Section B.4.3.3.4, "Analysis of Results, Documentation, and Treatment of Human Factor Engineering Issues," of the TR describes the process of documenting and using the findings from performance-based user testing. Specifically, it states that an HFE test and evaluation team analyzes the testing data. Additionally, it states that this team identifies issues and enters those issues into HFEITS, in addition to also preparing a test report. The test report is described as including summarized data, findings, and recommendations for resolutions. The NRC staff has determined that TerraPower's plan for HSI design addresses the capture of conclusions from performance-based tests, as well as the impact of those conclusions on design decisions and, therefore, concludes that criterion 8.4.6.2(3) is met.

7.7 Overall Conclusion for the HSI Design Element

The NRC staff concludes that, subject to the limitations and conditions contained in this evaluation, TerraPower's plan for HSI design, as described by the TR, is generally consistent with the relevant criteria of NUREG-0711. The associated results of this plan's implementation can be reviewed by the NRC staff when a future HSI design RSR has been provided.

8.0 PROCEDURE DEVELOPMENT

Procedures support and guide how plant personnel interact with the plant and respond to plant-related events. The NRC staff's objective in the review of this element is to confirm that the applicant's procedure development program incorporates HFE principles and design requirements to facilitate the development of procedures that will be technically accurate, comprehensive, explicit, easy to utilize, and validated. Furthermore, an additional staff objective in the review of this element is to evaluate conformance with the requirements of 10 CFR 50.34(f)(2)(ii). The NRC staff evaluated the HFEPP using the relevant review criteria in NUREG-0711, section 9.4, "Review Criteria," and the results of the NRC staff's evaluation are discussed below in sections 8.1 through 8.9. Per NUREG-0711, there is no associated RSR expected for this element.

NUREG-0711, section 9, "Procedure Development," references the acceptance criteria in chapter 13, "Conduct of Operations," of NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR [light water reactor] Edition" [24]. Thus, a complete review of this element necessarily entails implementing the reviews of NUREG-0800, sections 13.5.1.1, "Administrative Procedures – General," [25] and 13.5.2.1, "Operating and Emergency Operating Procedures," [26]. While NUREG-0800 is generally applicable only to LWRs, DANU-ISG-2022-05 provides specific guidance for non-light water reactors regarding the use of NUREG-0800, sections 13.5.1.1 and 13.5.2.1. However, the complete materials to be reviewed under NUREG-0800, sections 13.5.1.1 and 13.5.2.1, are not expected to be available until an OLA is submitted. Therefore, while the NRC staff evaluated the HFEPP using NUREG-0711, section 9, to the extent practical, the completion of the related NUREG-0800, sections 13.5.1.1 and 13.5.2.1, reviews remain an incomplete aspect of the NUREG-0711 review methodology that is addressed in the "Limitations and Conditions" section of this evaluation.

8.1 <u>Procedure Program Scope (Criterion 9.4(1))</u>

Criterion 9.4(1) states that the scope of the applicant's procedure development program should include the generic technical guidelines (GTG) for emergency operating procedures (EOPs), plant and system operations (including startup, power, and shutdown operations), test and maintenance, surveillance testing, abnormal and emergency operations, and alarm response.

Section 5.8 of the TR states that the PDP addresses procedures for plant and system operations across startup, normal, and shutdown conditions, as well as for maintenance, inspection, and testing. Additionally, it is stated that the PDP includes symptom-based EOPs, event-based abnormal operating procedures (AOPs), and alarm response procedures. During the audit, TerraPower clarified that the process of obtaining vendor support for the development of the EOPs is ongoing and that technical guidelines will be produced for those EOPs. However, TerraPower indicated that a decision has not yet been made regarding whether site-specific or GTGs will be developed for the EOPs, and that this decision is not expected to be made until approximately one year from the present time. The NRC staff has determined that TerraPower's plan for procedure development includes appropriate categories of procedures and that further evaluation of this area (including that related to GTGs, as relevant) can be completed in conjunction with a future OLA review.

8.2 <u>Basis for Developing Procedures (Criterion 9.4(2))</u>

Criterion 9.4(2) states that the applicant should identify the basis for developing procedures, which should include plant design bases, system-based technical requirements and specifications, results of TAs, important HAs, initiating events to be considered in the EOPs (including those in the design bases), the GTG for EOPs, and appropriate HFE of procedures. Section 5.8 of the TR discusses that the application of HFE principles is an objective of procedure development. The PDP is described, in part, as specifying inputs for procedure development. As discussed earlier in this evaluation, section 3.1 of the TR describes **[[**

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During the audit, TerraPower clarified that the process of obtaining vendor support for the development of the EOPs is ongoing and that technical guidelines will be produced for the EOPs. However, TerraPower indicated that a decision has not yet been made regarding whether site-specific or GTGs will be developed for the EOPs, and that this decision is not expected to be made until approximately one year from the present time. The NRC staff has determined that TerraPower's plan for procedure development identifies the basis for developing procedures and that further evaluation of this area (including that related to GTGs, as relevant) can be completed in conjunction with a future OLA review.

8.3 Writer's Guide (Criterion 9.4(3))

Criterion 9.4(3) states that the applicant should develop a writer's guide to establish the process for developing technical procedures that are complete, accurate, consistent, and easy to understand and follow. Section 5.8 of the TR states that a procedure writer's guide will be developed that addresses each type of procedure. The writer's guide is described as establishing criteria such that the procedures developed with it will be consistent in both style and content, with consideration of industry good practices. The NRC staff has determined that TerraPower's plan for developing a procedure writer's guide is consistent with supporting the development of adequate procedures and, therefore, concludes that criterion 9.4(3) is met.

8.4 Procedure Elements (Criterion 9.4(4))

Criterion 9.4(4) states that the applicant's procedures should contain elements that include title and identifying information, statement of applicability and purpose, prerequisites, precautions, important HAs, limitations and actions, acceptance criteria, check off lists, and reference material, as applicable.

Section 5.8 of the TR describes that the procedure writer's guide establishes criteria such that procedures developed with it will be consistent in organization and style. It is stated that the writer's guide provides instructions for procedure content, format, the way procedure steps should be written, and terminology used. During the audit, a copy of the TerraPower procedure ADI-RMD-102, "Procedure Writer's Manual," revision 1, was made available to the NRC staff. The NRC staff notes that the guide addressed, in part, the following: title and identifying information; applicability and purpose; procedural structure; writing style and wording conventions; prerequisites, limitations, cautions, and warnings; level of use determination (i.e., information, reference, or continuous use); operator actions (including those which are immediate in nature); acceptance criteria; data collection, signoffs (including independent verifications), and place keeping; reference material; and review guidelines. The NRC staff has determined that TerraPower's procedure writer's guide addresses appropriate procedure elements, is expected to yield procedures which contain those elements, and that further evaluation of this area can be completed in conjunction with a future OLA review.

8.5 Symptom-based GTGs and EOPs (Criterion 9.4(5))

Criterion 9.4(5) states that the applicant should develop symptom-based GTG and EOPs with clearly specified entry conditions. Section 5.8 of the TR states that the PDP includes symptom-based EOPs. During the audit, TerraPower clarified that the process of obtaining vendor support for the development of the EOPs is ongoing and that technical guidelines will be produced for the EOPs. However, TerraPower stated that a decision has not yet been made regarding whether site-specific or GTGs will be developed for the EOPs, and that this decision is not expected to be made until approximately one year from the present time. The NRC staff has determined that TerraPower's plan for procedure development includes symptom-based EOPs and that further evaluation of this area (including that related to GTGs, as relevant) can be completed in conjunction with a future OLA review.

8.6 Procedure Verification and Validation (Criterion 9.4(6))

Criterion 9.4(6) states that the applicant should verify that procedures are correct and that they should conduct V&V of procedures.

As discussed earlier in this evaluation, section 3.1 of the TR describes **[[**

]] The NRC staff has determined that TerraPower's plan for the validation and verification of procedures addresses the need to ensure that procedures are correct and that the planned grading of these validation activities appropriately considers both safety and risk insights. Therefore, the NRC staff concludes that criterion 9.4(6) is met.

8.7 Computer-based Procedures (Criterion 9.4(7))

Criterion 9.4(7) states that the applicant's computer-based procedures should be consistent with the design review guidance in NUREG-0700, section 8, "Computer-based Procedure System," and in section 1 of DI&C-ISG-5[8]. Section 5.7.2 of the TR states that the HFE COO document contains the concept for computer-based procedures and includes references to standards such as IEEE 1786-2022. The NRC staff notes that the IEEE 1786-2022 standard addresses HFE considerations associated with computer-based procedures in a manner that would be expected to contribute to an adequate finalized design. The NRC staff has determined that TerraPower's

[8] This ISG guidance was incorporated into NUREG-0800, chapter 18, revision 3.

plan for the development of computer-based procedures includes the application of reasonable HFE standards and, therefore, concludes that criterion 9.4(7) is met.

8.8 Procedure Control (Criterion 9.4(8))

Criterion 9.4(8) states that the applicant should have a plan for maintaining procedures and controlling updates. During the audit, TerraPower confirmed that they will conform to the requirements in NQA-1-2015, “Quality Assurance Requirements for Nuclear Facility Applications,” [27] and ANSI/ANS-3.2-2012, “Managerial, Administrative, and Quality Assurance Controls for the Operational Phase of Nuclear Power Plants,” [28] (with the exception that the 2015 version of NQA-1 will be used instead of the 2008 version referenced in ANSI/ANS-3.2-2012) for procedure maintenance and development. TerraPower also clarified that the commitment for TerraPower to conform to the requirements of NQA-1-2015 is contained in section 5 of TR TP-QA-PD-0001, revision 14-A.

TP-QA-PD-0001, revision 14-A, section 5, “Instructions, Procedures, and Drawings,” states, in part, that “quality assurance personnel shall review and approve procedures for performance of safety related work to ensure that quality requirements for the work are appropriately described.” Section 6, “Document Control,” of TP-QA-PD-0001, revision 14-A, discusses document controls, as well as the controls associated with changes to documents. The described measures include, in part, the identifying documents that are subject to controls, establishing an electronic document management system to maintain current revisions, and identifying individuals responsible for the preparation, review, and approval of controlled documents. Additionally, it states that revisions to documents shall be reviewed and approved according to supporting procedures, with changes being reviewed and approved by the same organization(s) that performed the original approval (except when another organization has been formally designated to do so). Both section 5 and section 6 include commitments to NQA-1-2015.

Based on the above, the NRC staff has determined that TerraPower’s plan for procedure development addresses maintaining procedures and controlling updates and, therefore, concludes that criterion 9.4(8) is met.

8.9 Access to Procedures (Criterion 9.4(9))

Criterion 9.4(9) states that the applicant should evaluate the physical means by which personnel access and use procedures, especially during operational events. Section 5.8 of the TR states the MCR HSIs will be designed to support use of computer-based procedures. Additionally, it states that both the MCR and RSC will contain storage space for hardcopy sets of operating procedures. The NRC staff has determined that TerraPower’s plan for procedure development addresses the physical availability of procedures, including during those operational events that could MCR access (i.e., by also providing for the availability of procedures at the RSC) and, therefore, concludes that criterion 9.4(9) is met.

8.10 Overall Conclusion for the Procedure Development Element

The NRC staff concludes that, subject to the limitations and conditions contained in this evaluation, TerraPower’s plan for procedure development, as described by the TR, is generally consistent with the relevant criteria of NUREG-0711. The associated results of this plan’s implementation can be reviewed by the NRC staff in conjunction with a future OLA.

9.0 TRAINING PROGRAM DEVELOPMENT

Training programs are important in ensuring that plant personnel can safely and reliably operate nuclear power plants by providing personnel with the knowledge, skills, and abilities needed to perform their roles and responsibilities. The NRC staff's objective in the review of this element is to verify that the applicant will employ a SAT for developing personnel training, an approach that is required by 10 CFR 50.120(b)(2) and contains the five elements listed in 10 CFR 55.4. The NRC staff evaluated the HFEPP using the relevant review criteria in NUREG-0711, section 10.4, "Review Criteria," and the results of the NRC staff's evaluation are discussed below in sections 9.1 through 9.7. Per NUREG-0711, there is no associated RSR expected for this element.

NUREG-0711, section 10, "Training Program Development," references the acceptance criteria of NUREG-0800, chapter 13. Thus, a complete review of this element would entail a review of a comparable scope to that of NUREG-0800, section 13.2.1, "Reactor Operator Requalification Program; Reactor Operator Training," [29] and section 13.2.2, "Non-Licensed Plant Staff Training," [30]. While NUREG-0800 generally applies only LWRs, DANU-ISG-2022-05 provides review guidance of a similar scope to these sections for non-light water reactors. Specifically, DANU-ISG-2022-05, section 11.1.3.2, "Licensed Operator Initial and Continuing (Requalification) Training," addresses licensed operator initial and continuing training, sections 11.1.3.1, "Training for Plant Staff," and 11.1.3.4, "Non-licensed Personnel Training," address plant staff training, and section 11.2, "Staff Review Guidance – Acceptance Criteria," contains related acceptance criteria for these topics.

However, the complete materials to be reviewed within these areas are not expected to be available until an OLA is submitted. Therefore, while the NRC staff evaluated the HFEPP using NUREG-0711, section 10, to the extent practical, the completion of the full review scope remains an incomplete aspect of the NUREG-0711 review methodology that is addressed in the "Limitations and Conditions" section of this evaluation.

9.1 <u>General Approach (Criteria 10.4.1(1)-(3))</u>

9.1.1 Systematic Approach to Training (Criterion 10.4.1(1))

Criterion 10.4.1(1) states that the applicant should develop a systematic approach to the training of plant personnel as defined in 10 CFR 55.4, "Definitions," and as required by 10 CFR 50.120, "Training and qualification of nuclear power plant personnel." Section 5.9 of the TR states that a TPDP will be established to specify a systematic approach to training (SAT). The TPDP is further described as incorporating the stages of a SAT, including analysis, design, development, implementation, and evaluation. The NRC staff notes that these stages correspond to the SAT elements defined under 10 CFR 55.4. The NRC staff has determined that TerraPower's plan for training program development incorporates a SAT and, therefore, concludes that criterion 10.4.1(1) is met.

9.1.2 Training Program Scope (Criterion 10.4.1(2))

Criterion 10.4.1(2) states that the overall scope of the applicant's training program should include categories of personnel to be trained, specific plant conditions, specific operational activities, and use of the HSIs. Section 5.9 of the TR describes the TPDP as specifying that a

SAT-based training approach be applied to the positions included in the minimum staff complement described in section 5.4 of the TR. Section 5.4 of the TR, in turn, states that a staffing analysis process will be used to systematically determine the minimum staff complement. Section 5.9 of the TR further describes, in part, that the SAT-based training program determines the training needed for the specified job positions based on assigned tasks, analyzes those tasks to determine the required abilities, uses those required abilities to support training design, and provides assurance that plant personnel have the abilities needed to perform their roles and responsibilities.

The NRC staff notes that this methodology is adaptable in nature and generally bounds specific plant conditions, operational activities, and use of facility HSIs. During the audit, TerraPower clarified that compliance with 10 CFR 50.120 will be addressed via the PSAR. The NRC staff has determined that TerraPower's training program will have an adequate scope and that review of the categories of personnel covered by the training program can be deferred until review of the OLA.

9.1.3 Job Qualifications (Criterion 10.4.1(3))

Criterion 10.4.1(3) states that the applicant's training program should provide reasonable assurance that personnel have qualifications commensurate with the performance requirements of their jobs. Section 5.9 of the TR describes, in part, that the SAT-based training program determines the training needed for specific job positions based on assigned tasks, analyzes those tasks to determine the required abilities, uses those required abilities to support training design, and provides assurance that plant personnel have the abilities needed to perform their roles and responsibilities. Furthermore, it states that the TPDP addresses the requirements and guidance provided in RG 1.8, which endorses ANSI/ANS-3.1-2014. The NRC staff has determined that TerraPower's training program addresses personnel qualifications using methods (i.e., SAT-based training and RG 1.8) that the NRC staff have previously determined to be acceptable and, therefore, concludes that criterion 10.4.1(3) is met.

9.2 Organization of Training (Criteria 10.4.2(1)-(3))

9.2.1 Roles in Training Development (Criterion 10.4.2(1))

Criterion 10.4.2(1) states that the applicant should define the roles of all organizations for developing the training requirements, training information sources, and materials for training, and thereafter, implementing the training program. Section 4.1 of the TR describes the roles and responsibilities within the HFE organization, including that of the HF operations/maintenance team role in training program development and coordination of training issues. During the audit, TerraPower clarified that they intend to obtain accreditation of their training program through the Institute of Nuclear Power Operations (INPO). Additionally, TerraPower indicated that they plan to achieve training program accreditation within 18 months of initial fuel load. The NRC staff notes that accreditation via INPO's National Academy for Nuclear Training (NANT) represents an acceptable method of meeting certain requirements associated with SAT-based training programs.[9] Additionally, the NRC staff's review of an OLA using DANU-ISG-2022-05 would entail verification that SAT-based training programs were established and, as relevant, whether

[9] The "Memorandum of Agreement Between the Institute of Nuclear Power Operations and the U.S. Nuclear Regulatory Commission," dated December 1, 2022 (ML23026A093), discusses that the NRC recognizes NANT accreditation as being an acceptable means of meeting the requirements of 10 CFR 50.120 and 10 CFR Part 55 as they relate to the use of SAT-based training programs.

NANT accreditation was obtained. The NRC staff has determined that review of TerraPower's definition of training-related roles can be deferred until review of the OLA.

9.2.2 Training Organization Qualifications (Criterion 10.4.2(2))

Criterion 10.4.2(2) states that the applicant should define the qualifications of organizations and personnel involved in developing and conducting training. Section 5.9 of the TR states that the TPDP addresses the guidance provided in RG 1.8. The NRC staff notes that this standard describes an approach to the qualifications of training management, supervision, and instructors which the NRC staff have previously determined to be acceptable. The NRC staff has determined that TerraPower's plan for personnel qualifications addresses the qualifications of the training organization and, therefore, concludes that criterion 10.4.2(2) is met.

9.2.3 Facilities and Resources (Criterion 10.4.2(3))

Criterion 10.4.2(3) states that the applicant should define the facilities and resources needed to satisfy the requirements of the training program (e.g., plant-referenced, full-scope simulators). During the audit, TerraPower confirmed that they plan to establish a full-scope, plant-referenced simulator, in addition to obtaining accreditation of their training program through INPO within 18 months of initial fuel load. The NRC staff has determined that review of TerraPower's training-related facilities and resources, including a plant-referenced simulator or Commission-approved simulator, can be deferred until the review of the OLA.

9.3 <u>Learning Objectives (Criteria 10.4.3(1)-(2))</u>

9.3.1 Basis for Learning Objectives (Criterion 10.4.3(1))

Criterion 10.4.3(1) states that the applicant should derive learning objectives from the analysis describing the desired performance after training. This analysis should include, but not be limited to, the training needs identified in the licensing basis, OER, FRA/FA, TA, TIHA, HSI design, plant procedures, and V&V. Section 5.9 of the TR states that the TPDP specifies the use of a SAT and that learning objectives will develop under the design element of a SAT-based process. The NRC staff notes that a SAT is required by 10 CFR 50.120(b)(2) and represents an acceptable methodology for the development of learning objectives. The NRC staff has determined that TerraPower's plan for training addresses the development of learning objectives and, therefore, concludes that criterion 10.4.3(1) is met.

9.3.2 Adequacy of Learning Objectives (Criterion 10.4.3(2))

Criterion 10.4.3(2) states that the applicant's learning objectives for personnel training should address the knowledge and skill needs and attributes of all relevant dimensions of the trainee's job, such as interactions with the plant, the HSIs, and other personnel. Section 5.9 of the TR describes that the analysis stage of the SAT process determines the training needed for job positions based on assigned tasks, with the tasks being identified through TAs. Tasks that are selected for training are analyzed to determine required skills, knowledge, and abilities. The design stage of the SAT process is then used to develop learning objectives based upon these inputs. The NRC staff notes that a SAT is required by 10 CFR 50.120(b)(2) and represents an acceptable methodology for the development of learning objectives. The NRC staff has determined that TerraPower's plan for the development of learning objectives addresses relevant task needs and, therefore, concludes that criterion 10.4.3(2) is met.

9.4 Design of the Training Program (Criteria 10.4.4(1)-(2))

9.4.1 Training on Learning Objectives (Criterion 10.4.4(1))

Criterion 10.4.4(1) states that the applicant should define how learning objectives will be conveyed to the trainee. Section 5.9 of the TR describes that learning objectives are developed during the design stage of the SAT process and that a plan for training (to include methods and settings) is established. In the development stage of the SAT, lesson plans, training materials, and assessment tests are established with instructors delivering the training to trainees during the subsequent implementation stage of SAT. The NRC staff notes that a SAT is required by 10 CFR 50.120(b)(2) and represents an acceptable approach for training development. The NRC staff has determined that TerraPower's plan for training addresses how learning objectives will be conveyed to trainees and, therefore, concludes that criterion 10.4.4(1) is met.

9.4.2 Simulator Training (Criterion 10.4.4(2))

Criterion 10.4.4(2) states that the applicant's training of reactor operators using nuclear power plant simulation facilities should conform to RG 1.149, "Nuclear Power Plant Simulation Facilities for Use in Operator Training, License Examinations, and Applicant Experience Requirements," [31], which endorses ANSI/ANS-3.5-2009, "Nuclear Power Plant Simulators for use in Operator Training and Examination," [32] as well as that the applicant should provide the details of the program for simulator training, including length of time (weeks) and a description of the simulation facility as required by 10 CFR 55.45(b) and 10 CFR 55.46, "Simulation facilities." During the audit, TerraPower clarified their intention for the simulator facility to model the initial MCR design and, later, the as-built MCR. TerraPower also stated that they intend for the training simulator to comply with the requirements of 10 CFR 55.46 as they relate to plant-referenced simulators and continued assurance of simulator fidelity. The NRC staff notes that establishment of a plant-referenced simulator is not expected to occur prior to completion of the HFE design of the MCR and, since the simulator will be used to support operator licensing, further details regarding the training simulator are not required at this time. The NRC staff has determined that review of TerraPower's program for simulator-based training, including any commitments associated with either a plant-referenced or Commission-approved simulator, can be deferred until review of the OLA.

9.5 Content of the Training Program (Criteria 10.4.5(1)-(4))

9.5.1 Job Task Training (Criterion 10.4.5(1))

Criterion 10.4.5(1) states that the applicant's training of factual knowledge should be taught using actual tasks so that personnel learn to apply it in the work environment. Section 5.9 of the TR describes that the analysis stage of the SAT process determines the training needed for job positions based on assigned tasks, with tasks being identified through a TA. The design stage of the SAT process is used to develop learning objectives based upon these inputs, with a plan for training (to include methods and settings) being established. In the development stage of SAT, lesson plans, training materials, and assessment tests are established, with instructors subsequently delivering the training to trainees during the implementation stage. The NRC staff has determined that TerraPower's plan for training uses actual job tasks as a basis and, therefore, concludes that criterion 10.4.5(1) is met.

9.5.2 Training Environment (Criterion 10.4.5(2))

Criterion 10.4.5(2) states that the applicant's training of skills should be structured so that the environment is consistent with the level of skill being taught. Section 5.9 of the TR describes that tasks that are selected for training are analyzed to determine required skills, knowledge, and abilities. The design stage of the SAT process is then used to develop learning objectives based upon these inputs and a plan for training that includes settings is established. The NRC staff has determined that TerraPower's plan for training addresses the selection of environments and, therefore, concludes that criterion 10.4.5(2) is met.

9.5.3 Decision-making (Criterion 10.4.5(3))

Criterion 10.4.5(3) states that the applicant's training should address rules for decision-making for plant systems, HSIs, and procedures. More specifically, this criterion considers whether applicant training includes rules for accessing and interpreting information, as well as for interpreting the symptoms of failures of systems, HSIs, and procedures. The NRC staff notes that this type of information is typically found within "conduct of operations" procedural guidance which would be anticipated to be available in conjunction with an OLA. The NRC staff has determined that review of this criterion can reasonably be deferred until the review of an OLA.

9.5.4 Degraded Conditions Training (Criterion 10.4.5(4))

Criterion 10.4.5(4) states that the applicant's training for performance under degraded conditions should support personnel performance.

Section 5.2 of the TR describes that a defense-in-depth methodology is included within the FRA process which establishes functions with sufficient independence (including any needed control and instrumentation diversity) to assure adequate safety should failures or degradations occur. Additionally, section 5.2 of the TR states that certain defense line functions are specified as manual HAs, with the appropriateness of those manual HAs being confirmed by means of the AOF process. Section 5.6 of the TR states that the TA identifies task requirements to accomplish those functions that are allocated to humans (including any partial allocations made to humans). Section 5.9 of the TR describes that the analysis stage of the SAT process determines the training needed for job positions based on assigned tasks, with tasks being identified through TA. Tasks that are selected for training are analyzed to determine required skills, knowledge, and abilities. In the implementation stage of SAT, instructors deliver the training to trainees and the trainees are tested to determine if they have mastered objectives. The NRC staff has determined that TerraPower's plan for implementation of a SAT-based training approach should reasonably address the performance of identified tasks that may occur under degraded conditions and, therefore, concludes that criterion 10.4.5(4) is met.

9.6 <u>Evaluation and Modification of Training (Criteria 10.4.6(1)-(3))</u>

9.6.1 Evaluation of Training Effectiveness (Criterion 10.4.6(1))

Criterion 10.4.6(1) states that the applicant should define the methods and criteria of evaluation and assessment. Section 5.9 of the TR describes the implementation and evaluation stages of the SAT process. As part of the implementation stage, trainees are described as being tested to determine if they have mastered objectives, with the results of the testing being examined during the evaluation stage. The evaluation stage is, in turn, described as utilizing the review of training results, training feedback, and continual monitoring of work performance to examine training effectiveness. The NRC staff has determined that TerraPower's plan for training addresses the evaluation of training effectiveness and, therefore, concludes that criterion 10.4.6(1) is met.

9.6.2 Accuracy and Completeness of Training Material (Criterion 10.4.6(2))

Criterion 10.4.6(2) states that the applicant should define the methods for verifying the accuracy and completeness of the training course materials. Section 5.9 of the TR describes that lesson plans and instructional materials are created in the development stage of the SAT process, with the training package subsequently being reviewed, piloted on trainees, and revised if necessary. The NRC staff has determined that TerraPower's plan for training addresses the accuracy and completeness of training materials and, therefore, concludes that criterion 10.4.6(2) is met.

9.6.3 Updates and Modification to Training (Criterion 10.4.6(3))

Criterion 10.4.6(3) states that the applicant should establish procedures for refining and updating the content and conduct of training, including procedures for tracking modifications in the training courses.

Section 5.9 of the TR describes that the analysis stage of the SAT process determines the training needed for job positions, with the design stage then being used to develop a plan for training. The subsequent development stage of SAT establishes lesson plans, training materials, and assessment tests. The NRC staff notes that the SAT methodology represents an acceptable training approach, and that the SAT process is, by design, responsive to changes in training needs that may occur over time. During the audit, TerraPower confirmed their intention to obtain accreditation of their training program through INPO; the NRC staff notes that accreditation via INPO's NANT represents an acceptable method of meeting certain requirements associated with SAT-based training programs. The NRC staff has determined that TerraPower's plan for training addresses the development of training materials in a manner that should reasonably enable training updates and modifications by means of a SAT-based process and, therefore, concludes that criterion 10.4.6(3) is met.

9.7 <u>Periodic Retraining (Criteria 10.4.7(1)-(2))</u>

9.7.1 Provisions for Retraining (Criterion 10.4.7(1))

Criterion 10.4.7(1) states that the applicant's program should contain provisions to periodically retrain personnel. Section 5.9 of the TR states that the analysis stage of the SAT-based training process determines the training needed for specific job positions based upon assigned tasks, with factors including the difficulty, importance, and frequency of those tasks being used to inform decisions regarding periodic retraining. However, the NRC staff notes that complete information regarding the retraining of personnel, as required by the associated requirements of 10 CFR Part 50 and 10 CFR Part 55, is expected to be developed in conjunction with an OLA[10]. The NRC staff has determined that TerraPower's plan for training considers personnel retraining needs, and that further staff review can be deferred until an OLA.

9.7.2 Evaluation of Changes (Criterion 10.4.7(2))

[10] DANU-ISG-2022-05 includes licensed operator initial training, licensed operator requalification training, and non-licensed personnel training within its scope.

Criterion 10.4.7(2) states that the applicant should evaluate whether any changes in retraining are warranted following plant modernization programs. Section 5.9 of the TR describes that the analysis stage of the SAT process determines the training needed for job positions based on assigned tasks, with tasks being identified through TA. The NRC staff notes that a SAT is required by 10 CFR 50.120(b)(2) and represents an acceptable training approach, and that the SAT process is, by design, responsive to changes in training needs that may occur over time. During the audit, TerraPower confirmed their intention to obtain accreditation of their training program through INPO which, the NRC staff notes, represents an acceptable method of meeting certain requirements associated with SAT-based training programs. The NRC staff has determined that TerraPower's plan for training addresses the development of training materials in a manner that should, by means of a SAT-based process, reasonably address retraining needs associated with future plant modifications and, furthermore, that additional staff review can be deferred until the review of an OLA.

9.8 Overall Conclusion for the Training Program Development Element

The NRC staff concludes that, subject to the limitations and conditions contained in this evaluation, TerraPower's plan for training program development, as described by the TR, is generally consistent with the relevant criteria of NUREG-0711. The associated results of this plan's implementation can be reviewed by the NRC staff in conjunction with a future OLA.

10.0 HUMAN FACTORS VERIFICATION AND VALIDATION

The Verification and Validation (V&V evaluations determine whether an HFE design conforms to design principles and enables personnel to successfully and safely perform their tasks. This HFE element is comprised of HSI TSV, HFE design verification (DV), ISV, and HEDs resolution. The NRC staff's objective in the review of this element is to verify the adequacy of the overall V&V approach. The NRC staff evaluated the HFEPP using the relevant review criteria in NUREG-0711, section 11.4, "Review Criteria," and the results of the NRC staff's evaluation are discussed below in sections 10.1 through 10.4. It should be noted that, per NUREG-0711, an associated RSR is expected for this element, however, RSRs are not included as part of this HFEPP and will need to be submitted and reviewed as part of an OLA.

10.1 Sampling of Operational Conditions (Criteria 11.4.1.1 - 11.4.1.4)

10.1.1 Sampling Dimensions (Criteria 11.4.1.1(1)-(3))

10.1.1.1 Plant dimensions (Criterion 11.4.1.1(1))

Criterion 11.4.1.1(1) states that the plant conditions should include the following: normal operational events; I&C and HSI failures and degraded conditions; and transients and accidents.

Section 5.10 of the TR presents an overview of the HFE V&V plan, with appendix D of the TR describing the plan in greater detail. Section 5.10 of the TR discusses that an operational condition sampling approach is used to ensure that representative range of operating conditions is included in the scenarios used for ISV. Section D.1.2 of the TR describes that the scope of the V&V process includes hardware and software-based HSIs that are used for, in part, normal, abnormal, and emergency operations. Section D.4.2 of the TR discusses the minimum sample conditions which serve to ensure that an essential set of operations conditions are included within the V&V scope. **[[**

]] The NRC staff has determined that TerraPower's plan for V&V addresses the sampling of an adequate range of plant dimensions and, therefore, concludes that criterion 11.4.1.1(1) is met.

10.1.1.2 Types of Personnel Tasks (Criterion 11.4.1.1(2))

Criterion 11.4.1.1(2) states that the types of personnel tasks should include important HAs, important systems, and dominant accident sequences, manual initiation of protective actions, automatic system monitoring, OER-identified problematic tasks, the range of procedure guided tasks, the range of knowledge-based tasks, the range of human cognitive activities, and the range of human interactions.

Section D.4 of the TR describes the process of sampling operational conditions. Section D.4.1, "Task Analysis Graded Approach Output Information," of the TR states that the sampling strategy starts from the graded approach which incorporates risk insights during the TA and HSI design processes. Section D.4.2 of the TR establishes **[[**

]] Section D.4.3 of the TR discusses **[[**

]] Additionally, section D.4.3 of the TR also describes the sampling of tasks that include a range of human cognitive abilities (e.g., monitoring, diagnosing, decision-making, manipulations, and monitoring), communications, and human interactions.

The NRC staff has determined that TerraPower's plan for V&V addresses an appropriate scope and range of types of personnel tasks and, therefore, concludes that criterion 11.4.1.1(2) is met.

10.1.1.3 Situational Factors (Criterion 11.4.1.1(3))

Criterion 11.4.1.1(3) states that the situational factors or error-forcing contexts should include high-workload situations, varying-workload situations, fatigue situations, and environmental factors. Section D.4.2 of the TR establishes **[[**

]] Additionally, section D.4.3 of the TR describes representative sampling conditions that include situational factors of operationally difficult tasks identified via the OER, scenarios designed to generate human errors, varying crew sizes, both high and low workloads, varying workloads, circadian factors, and environmental factors (e.g., high noise, poor lighting, etc.). The NRC staff has determined that TerraPower's plan for V&V addresses appropriate situational factors and error-forcing contexts and, therefore, concludes that criterion 11.4.1.1(3) is met.

10.1.2 Identification of Scenarios (Criteria 11.4.1.2(1)-(2))

10.1.2.1 Combination of Sampled Results (Criterion 11.4.1.2(1))

Criterion 11.4.1.2(1) states that the applicant should combine the results of the sampling to identify a set of V&V scenarios to guide subsequent analyses.

Section D.4.2 of the TR establishes **[[**

]] Section D.4.4, “Sample Selection,” of the TR states that scenarios are selected from a representative population sample set which, together, will fulfill the minimum conditions. Section D.4.4 further describes **[[**

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The NRC staff has determined that TerraPower’s plan for V&V addresses the combining the results from sampling to identify a set of V&V scenarios and, therefore, concludes that criterion 11.4.1.2(1) is met.

10.1.2.2 Avoidance of Bias (Criterion 11.4.1.2(2))

Criterion 11.4.1.2(2) states that the applicant should not bias the scenarios by overly representing scenarios for which only positive outcomes are expected, scenarios that are relatively easy to conduct, or scenarios that are familiar and well-structured.

Section D.2.1, “Human Factors Engineering Verification and Validation Team Roles,” of the TR states that, to ensure V&V activities are free from bias, the HF engineers that conduct V&V activities must be different from those involved in the design process. Section D.6.4,” Human Factors Engineering Validation Scenario Set Identification and Development,” of the TR describes that ISV scenarios are developed using a structured process to ensure the minimization of bias. A provided example of these measures is coordination with operations training to avoid schedule overlap between given training topics and HFE ISV testing scenarios with related content. Section D.6.4.3 of the TR discusses that the sequence of events selected for scenarios incorporates realistic conditions to limit potential operator bias due to anticipated scenario progression. Additionally, section D.6.4.4, “Qualitative and Quantitative Scenario Attributes,” of the TR states **[[**

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Section D.6.4.8, “Measures Taken to Eliminate or Control Scenario Development Bias,” of the TR provides a description of measures that test personnel use to avoid sample bias during scenario development. These measures include, in part, procedural controls for scenario development and validation processes, use of a representative range of conditions during

scenarios, evaluation of scenario attributes and their distribution, and pilot studies. Furthermore, section D.6.4.9, "Scenario Set Review and Approval," discusses that scenario sets undergo a post-development review to identify biases, with the review specifically looking for 1) scenarios for which only positive outcomes are expected, 2) scenarios that are administratively easy to conduct, or 3) scenarios that are familiar and well structured.

Based on the above, the NRC staff has determined that TerraPower's plan for V&V addresses measures to avoid bias in scenarios and, therefore, concludes that criterion 11.4.1.2(2) is met.

10.1.3 Scenario Definition (Criteria 11.4.1.3(1)-(3))

10.1.3.1 Identification of Operational Conditions (Criterion 11.4.1.3(1))

Criterion 11.4.1.3(1) states that the applicant should identify operational conditions and scenarios to be used for HSI TSV, DV, and ISV. Section D.4 of the TR describes the process of sampling operational conditions for V&V activities. Section D.5.4.1, "Task Support Verification Acceptance Criteria," of the TR describes that the TSV process incorporates verification criteria that are identified during TA and provides the criteria against which HSIs are verified. Section D.5.5, "Human Factors Engineering Design Verification," of the TR describes that the DV process evaluates the HSI design against the HFE DRD to verify that the design complies with HFE design principles. Section D.6.4 of the TR describes that the scenarios used to exercise the selected operational conditions during ISV are governed by procedures which include requirements for the documentation of, in part, scenario objectives, initial conditions, events, and attributes. The NRC staff has determined that TerraPower's plan for V&V will identify the operational conditions and scenarios to be used during V&V activities and, therefore, concludes that criterion 11.4.1.3(1) is met.

10.1.3.2 Replication of Operator Tasks (Criterion 11.4.1.3(2))

Criterion 11.4.1.3(2) states that the applicant's scenarios should realistically replicate operator tasks in the tests; then, the findings from the test can be generalized to the plant's actual operations.

Section 5.10 of the TR describes ISV as an integrated and dynamic activity with simulated scenarios that represent a realistic and generalizable set of conditions. The process of sampling operational conditions for V&V activities is described in section D.4 of the TR, which incorporates an objective for HFE V&V results to be generalizable by means of ensuring that samples are broad and diverse in nature. Section D.6.4.2, "Initial Conditions," of the TR describes the use of scenario initial conditions that establish realism and section D.6.4.3 of the TR emphasizes the use of realistic events in ISV scenarios as a means of avoiding scenario predictability, recognizability, and potential bias. Additionally, section D.6.4.4 of the TR establishes attributes for scenarios, which include both realistic plant response and simulator modeling as qualitative attributes. Furthermore, section D.6.5, "Scenario Detailed Definition and Documentation," of the TR describes **[[**

]] The NRC staff has determined that TerraPower's plan for V&V addresses the realistic replication of operator tasks within scenarios and, therefore, concludes that criterion 11.4.1.3(2) is met.

10.1.3.3 Environmental Effects on Performance (Criterion 11.4.1.3(3))

Criterion 11.4.1.3(3) states that when the applicant's scenarios include work associated with operations remote from the MCR, the effects on personnel performance due to potentially harsh environments should be realistically simulated.
Section D.1.2 of the TR states that the HFE V&V process applies to both the NI RSC and local controls, including local field HSIs that support operations, protection systems, and plant safety. Section D.6.3.1.3 discusses that ISV scenarios model local tasks that are important to risk or safety, with scenario event guides incorporating factors associated with local operations to guide the performance of simulations. Additionally, risk-significant local control operations are described as being validated using simulations and mock-ups. Section D.6.5.12 discusses **[[**

]] The NRC staff has determined that TerraPower's plan for V&V addresses realism in simulations to account for the effects of environmental conditions in the field and, therefore, concludes that criterion 11.4.1.3(3) is met.

10.2 <u>Design Verification (Criteria 11.4.2.1 - 11.4.2.3)</u>

10.2.1 HSI Inventory and Characterization (Criteria 11.4.2.1(1)-(3))

10.2.1.1 Scope (Criterion 11.4.2.1(1))

Criterion 11.4.2.1(1) states that the applicant should develop an inventory of all HSIs that personnel require to complete the tasks covered in the validation scenarios that were identified by the applicant's sampling of operational conditions.

Section D.4 of the TR describes the process of sampling operational conditions for V&V activities. Section D.5, "Human Factors Engineering Verification," of the TR states that HFE verification activities confirm that the design fulfills the task requirements from the TA (verified during TSV) and complies with design requirements from the HFE DRD (verified during DV). Section D.5.1, "Human Factors Engineering Verification Inputs," of the TR discusses that the inputs for HFE verification activities include an HSI inventory, along with the tasks associated with each HSI. Section D.5.5 of the TR describes that the DV process evaluates the HSI design against the HFE DRD to verify that the design complies with HFE design principles. Specifically, DV is described as focusing on, in part, static and dynamic HSI features, workstations, interface management features, and degraded HSI conditions. Section D.5.5.2 of the TR describes that the designed HSIs, as defined in the HSI inventory, are verified against the HFE DRD.

The NRC staff has determined that TerraPower's plan for V&V addresses the development of an appropriate inventory of the required HSIs and, therefore, concludes that criterion 11.4.2.1(1) is met.

10.2.1.2 HSI Characterization (Criterion 11.4.2.1(2))

Criterion 11.4.2.1(2) states that the applicant's inventory should describe the characteristics of each HSI within the scope of the verification.

Section D.5.1 of the TR discusses that the inputs for HFE verification activities include an HSI inventory that contains the HSIs and a characterization that describes the HSIs. The HSI inventory is derived from the user interface specification for each plant system, while the characterization includes a unique identification code, plant system, associated tasks, and type of HSI (e.g., hardware, software, alarm, computerized procedure, etc.). Section D.5.5.1, “Human Factors Engineering Design Verification Acceptance Criteria,” of the TR describes that the HFE DRD contains the applicable criteria for HSI design, as well as that the acceptance criteria used within DV include verification that HSI characteristics meet design requirements. Additionally, section D.5.5.2 of the TR states that “designed HSIs and their characteristics (as defined in the HSI inventory and characterization) are verified against the HFE DRD.” The NRC staff has determined that TerraPower’s plan for V&V addresses the development of an HSI inventory and, therefore, criterion 11.4.2.1(2) is met.

10.2.1.3 Inventory Verification (Criterion 11.4.2.1(3))

Criterion 11.4.2.1(3) states that the applicant should verify the inventory description of HSIs to ensure that it accurately reflects their current state. The NRC staff considered several aspects of the HFEPP to determine whether the V&V plan has a process for verifying the accuracy of the HSI inventory. First, section D.5.1 of the TR describes that the HSI inventory is derived from each plant system user interface specification. Second, section D.1.1 of the TR discusses that the HFE V&V process incorporates an iterative cycle between V&V activities and HSI design processes. Section D.5.1 of the TR further states that HEDs identified during HFE verification activities (which are used to track issues for resolution) are entered into HFEITS. Third, section D.5.3 of the TR describes tools used for HFE verification, which include the use of high-fidelity, part-task, and full-scope simulators to verify that HSI designs correctly represent system and plant status, as well as control response.

The NRC staff notes that these processes, considered as an integrated process, would be expected to accomplish the verification of HSI inventory accuracy to the current state. The NRC staff has determined that TerraPower’s plan for V&V addresses verification of HSI inventory accuracy and, therefore, concludes that criterion 11.4.2.1(3) is met.

10.2.2 HSI Task Support Verification (Criteria 11.4.2.2(1)-(4))

10.2.2.1 Task Support Verification Criteria (Criterion 11.4.2.2(1))

Criterion 11.4.2.2(1) states that the applicant should base the HSI task support criteria on the alarms, controls, displays, and task support needed by personnel to complete their tasks as identified by the applicant’s TA. Section D.5.1 of the TR states that the inputs for HFE verification activities include a task support inventory which is developed from the TA. This task support inventory is broadly described as containing the alarms, controls, and indications necessary for the support of tasks. Section D.5.4.1 of the TR provides the acceptance criteria that are used within the TSV process in comparing HSI elements (i.e., alarms, controls, and indications) that were identified by the TA to those included in the final design. The NRC staff has determined that TerraPower’s plan for V&V addresses HSI task support criteria that are based on the TA and, therefore, concludes that criterion 11.4.2.2(1) is met.

10.2.2.2 Task Support Verification General Methodology (Criterion 11.4.2.2(2))

Criterion 11.4.2.2(2) states that the applicant should compare the HSIs and their characteristics (as defined in the HSI inventory and characterization) to the needs of personnel identified in the TA for the defined sampling of operational conditions (as noted in section 11.4.1, “Sampling of Operational Conditions,” of NUREG-0711). Section D.4 of the TR describes the process of sampling operational conditions for V&V activities. Section D.5.4.1 describes that the TSV process incorporates verification criteria that are identified during TA and provides the criteria against which HSIs are verified. These criteria include the acceptance criteria that are used within the TSV process in comparing HSI elements (i.e., alarms, controls, and indications) that were identified by the TA to those included in the final design. The NRC staff has determined that TerraPower's plan for V&V addresses the comparison of the HSIs inventory and characteristics to the needs of personnel and, therefore, concludes that criterion 11.4.2.2(2) is met.

10.2.2.3 Task Support Verification HED Identification (Criterion 11.4.2.2(3)) and Documentation (Criterion 11.4.2.2(4))

Criterion 11.4.2.2(3) states that the applicant should identify and document an HED when an HSI needed for task performance is unavailable, HSI characteristics do not match the requirements of personnel, or when HSIs are available but are not needed for any task. Criterion 11.4.2.2(4) states that the applicant should document HEDs to identify the HSI, the tasks affected, and the basis for the deficiency (i.e., what aspect of the HSI was identified as not meeting task requirements). Section D.5.4.3 of the TR describes that the outputs of the TSV process include HEDs that document both deficiencies and unnecessary components that were identified. Specifically, it states that HEDs are entered into the HFEITS to document unsupported (or partially supported) tasks, HSI characteristics that are inconsistent with task requirements, unnecessary HSI components, and instances of identified discrepancies or deficiencies in TA outputs. The NRC staff has determined that TerraPower's plan for V&V addresses the identification and documentation of HEDs for issues identified during TSV and, therefore, concludes that criterion 11.4.2.2(3) is met.

10.2.3 HFE Design Verification (Criteria 11.4.2.3(1)-(4))

10.2.3.1 DV Criteria (Criterion 11.4.2.3(1))

Criterion 11.4.2.3(1) states that the applicant should base the criteria used for HFE DV on HFE guidelines. Section 5.7.4 of the TR describes that the HFE DRD includes, in part, requirements for information displays, user interfaces, controls, alarms, safety parameter monitoring, computer-based procedures, workstations, and labeling. Section 5.7.4 of the TR states that the HFE DRD is being developed to comply with codes, standards, and HFE best practices (e.g., NUREG-0700). Section D.5.5 of the TR describes that the DV process evaluates the HSI design against the HFE DRD to verify that the design complies with HFE design principles. Section 5.5.1 of the TR states the that the HFE DRD contains the acceptance criteria used in the DV of the HSI design. The NRC staff has determined that TerraPower's plan for V&V addresses the use of HFE guidelines within DV and, therefore, concludes that criterion 11.4.2.3(1) is met.

10.2.3.2 DV General Methodology (Criterion 11.4.2.3(2))

Criterion 11.4.2.3(2) states that the applicant's HFE DV methodology should include procedures for comparing the characteristics of the HSIs with HFE guidelines, procedures for determining whether the HSI is "acceptable" or "discrepant," for each guideline and procedures for evaluating whether an HED is a potential indicator of additional issues. Section D.5.5.2 of the TR discusses DV evaluation methods. The general approach is described as consisting of verifying designed HSIs and their characteristics against the HFE DRD, with individual HSI features being compared to the associated design requirements of the HFE DRD. For each HSI element that is evaluated, documentation includes the HFE DRD requirements that were applied, as well as whether the HSI element passed or failed each requirement. Where HEDs are identified, the HFE verifier describes the non-compliance to capture the specific deficiency or issue. Section 5.5.3 of the TR further states that HEDs involving standardized features are assessed to determine whether discrepancies across similar HSIs may exist. The NRC staff has determined that TerraPower's plan for V&V addresses evaluation of HSIs against HFE guidelines and, therefore, concludes that criterion 11.4.2.3(2) is met.

10.2.3.3 DV HED identification (Criterion 11.4.2.3(3)) and Documentation (Criterion 11.4.2.3(4))

Criterion 11.4.2.3(3) states that the applicant should identify an HED when a characteristic of the HSI is "discrepant" from a guideline. Criterion 11.4.2.3(4) states that the applicant should document HEDs in terms of the HSI involved and how its characteristics depart from a particular guideline. Section 8.1 of the TR describes that HEDs are placed into HFEITS when a deviation from a human factors DRD requirement is discovered during DV. Section D.5.5.2 of the TR discusses the DV of designed HSIs and their characteristics against the HFE DRD. For each HSI element that is evaluated during DV, documentation includes the HFE DRD requirements that were applied, as well as whether the HSI element passed or failed each requirement. Where HEDs are identified, the HFE verifier describes the non-compliance to capture the specific deficiency or issue. The NRC staff has determined that TerraPower's plan for V&V addresses the identification of HEDs related to HSI discrepancies and the appropriate documentation of HEDs identified during DV and, therefore, concludes that criterion 11.4.2.3(3) is met.

10.3 <u>Integrated System Validation (Criteria 11.4.3.1 - 11.4.3.8)</u>

10.3.1 Validation Team (Criterion 11.4.3.1(1))

Criterion 11.4.3.1(1) states that the applicant should describe how the team performing the validation has independence from the personnel responsible for the actual design. Section D.2.1 of the TR states that 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." The NRC staff has determined that TerraPower's plan for V&V addresses the independence of personnel who conduct V&V activities and, therefore, concludes that criterion 11.4.3.1(1) is met.

10.3.2 Test Objectives (Criterion 11.4.3.2(1))

Criterion 11.4.3.2(1) states that the applicant should develop detailed test objectives to provide evidence that the integrated system adequately supports plant personnel in safely operating the plant. Section D.6.4 of the TR states that procedures related to the performance of ISV will include guidance for the development of scenario objectives. Section D.6.4.1 of the TR describes that these predetermined objectives will be used in evaluating the ability of operators to effectively use the HSI in responding to events during scenarios. Specifically, observations during scenarios will be used to assess, in part, the ability of operators to conduct integrated plant operations, utilize the integrated HSI, diagnose abnormal plant conditions, use appropriate procedures, and communicate effectively. Additionally, there will also be objectives related to the specific operational conditions and events contained within the scenarios. The NRC staff has determined that TerraPower's plan for V&V addresses the development of ISV test objectives and, therefore, concludes that criterion 11.4.3.2(1) is met.

10.3.3 Validation Testbeds (Criteria 11.4.3.3(1)-(9))

10.3.3.1 Interface Completeness and Fidelity (Criteria 11.4.3.3(1) – (7))

Criteria 11.4.3.3(1) - (7) state that the applicant's testbed should represent the integrated system, in addition to also having interface physical fidelity, interface functional fidelity, environmental fidelity, data completeness fidelity, data content fidelity, and data dynamics fidelity. NUREG-0711, section 11.4.3.3, "Validation Testbeds," provides guidance that one approach that can be used to acceptably meet these criteria is to use a testbed that complies with ANSI/ANS-3.5-2009. Section 5.10 of the TR discusses that the assessment of testbed fidelity is informed by standards, such as IEEE 2411-2021, "IEEE Guide for Human Factors Engineering for the Validation of System Designs and Integrated Systems Operations at Nuclear Facilities" [33]. Section D.6.3.1.2, "Validation Testbed Requirements," of the TR (which also references IEEE 2411-2021) presents simulator fidelity requirements that must be met for the scope of the validation conducted. The NRC staff reviewed these simulator fidelity requirements and note that they are generally consistent with those described in Criteria 11.4.3.3(1) – (7) of NUREG-0711. The NRC staff also notes that IEEE 2411-2021 references ANSI/ANS-3.5-2009 for informing the preparation of a simulator test bed for use in validations.

The NRC staff further notes that, since establishment of a simulator that complies with ANSI/ANS-3.5-2009 would generally not be expected prior to the completion of the MCR design, the degree to which these standards are applied within the HFEPP is reasonable. As discussed previously, during the audit, TerraPower indicated that they will review their system design and ability to conform to RG 1.149, revision 4 (which endorses ANSI/ANS-3.5-2009). TerraPower stated that they plan to engage with the NRC staff on potential exceptions to this RG (or on the possible use of newer standards) at an appropriate point in the design.

Based on the above, the NRC staff has determined that TerraPower's plan for V&V reasonably addresses interface completeness and fidelity and, therefore, concludes that criteria 11.4.3.3(1)-(7) are met.

10.3.3.8 Verification of Human Performance Requirements (Criterion 11.4.3.3(8))

Criterion 11.4.3.3(8) states that for important HAs at complex HSIs remote from the MCR (e. g., a remote shutdown facility), where timely, precise actions are essential, the use of a simulator or mockup should be considered to verify that the requirements for human performance can be met. Section D.1.2 of the TR describes that the HFE V&V process includes both the NI RSC and local controls within its scope. Furthermore, section D.6.3.1.3 of the TR states that risk-significant local control operations are validated using simulations and mock-ups. The NRC staff has determined that TerraPower's plan for V&V addresses the consideration of mock-ups in the verification of important, remote HAs and, therefore, concludes that criterion 11.4.3.3(8) is met.

10.3.3.9 Conformance of Testbed to Required Characteristics (Criterion 11.4.3.3(9))

Criterion 11.4.3.3(9) states that the applicant should verify the conformance of the testbed to the testbed-required characteristics before validation tests are conducted. Section D.6.3.1.3 of the TR discusses that testbeds are verified at each phase of validation testing to ensure that fidelity requirements are met. Specifically, this is accomplished by confirming that the software and computers used for development of the simulator match what is to be installed the plant, with testbed verification occurring during pilot tests before validation. HSI changes are incorporated during system development such that the HSI design will be stabilized by the time the full-scope simulator is developed; this is used to ensure that the testbed will be consistent with the current design. The NRC staff has determined that TerraPower's plan for V&V addresses verification of the conformance of the testbed to required characteristics prior to validation tests and, therefore, concludes that criterion 11.4.3.3(9) is met.

10.3.4 Plant Personnel (Criteria 11.4.3.4(1)-(4))

10.3.4.1 Selection of Appropriate Personnel (Criterion 11.4.3.4(1))

Criterion 11.4.3.4(1) states that participants in the applicant's validation tests should be representative of plant personnel who will interact with the HSI. Section D.6.6, "Human Factors Engineering Validation Participant Selection," of the TR describes that the participants for early validation activities may be selected from among training staff, formerly licensed operators, procedure writers, and engineers (e.g., startup I&C, PRA, or HFE). During later ISV activities, the participants can subsequently include individuals enrolled in the initial licensed operator training. The NRC staff notes that this participant selection pool and approach is reasonable since operators who are licensed for the Natrium facility will not yet be available during the timeframe in which validation activities will primarily occur. The NRC staff has determined that TerraPower's plan for V&V addresses the selection of appropriate validation participants and, therefore, concludes that criterion 11.4.3.4(1) is met.

10.3.4.2 Representative Sampling of Participants (Criterion 11.4.3.4(2))

Criterion 11.4.3.4(2) states that to properly account for human variability, the applicant should use a sample of participants that reflects the characteristics of the population from which it is drawn. Section D.6.6 of the TR discusses that variables which contribute to variations in task performance are accounted for during the sampling of validation participants. Section D.6.6 of the TR further states that the population characteristics considered include operator licenses, qualifications, shift staffing, skills, experience, and minimum operations staffing. Additionally, it states that a minimum of three crews will be tested during full-scope simulator HSI testing. The NRC staff has determined that TerraPower's plan for V&V addresses validation participant sampling that reflects population characteristics and, therefore, concludes that criterion 11.4.3.4(2) is met.

10.3.4.3 Consideration of Staffing Levels (Criterion 11.4.3.4(3))

Criterion 11.4.3.4(3) states that in selecting personnel for participating in the tests, the applicant should consider the minimum shift staffing levels, nominal levels, and maximum levels, including shift supervisors, ROs, shift technical advisors, etc. Section D.6.6 of the TR describes that the participants for early validation activities may include formerly licensed operators and that later ISV activities can subsequently include individuals enrolled in the initial licensed operator training. It also states that that the population characteristics considered for validation include operator licenses, qualifications, shift staffing, and minimum operations staffing. Additionally, it states that a minimum of three crews will be tested during full-scope simulator HSI testing, with at least two SROs and two ROs in each crew.

As previously noted in this evaluation, section 5.4 of the TR describes a staffing analysis process that systematically determines the minimum staff complement. Appendix C of the TR describes the HFE staffing analysis plan. Section C.5.3 of the TR discusses the validation of nominal shift levels, minimal shift levels, and shift turnover. **[[**

]] During the audit, TerraPower clarified that TerraPower will seek an exemption via the OLA for the omission of the STA role. The NRC staff has determined that TerraPower's plan for V&V addresses variations in staffing levels and that the review of the justification for omission of the STA role can be deferred until the review of the OLA.

10.3.4.4 Avoidance of Bias (Criterion 11.4.3.4(4))

Criterion 11.4.3.4(4) states that the applicant should prevent bias in the sample of participants by avoiding the use of participants who are members of the design organization, who participated in prior evaluations, or who were selected for some specific characteristic. Section D.6.6.2, "Prevention of Participant Sampling Bias," of the TR states that participants are selected from a representative population using a randomized sampling methodology. Section D.6.6.2 of the TR describes that sampling bias is avoided in participant selection by excluding design organization personnel, individuals who participated in prior design evaluations, or participants selected for some specific characteristic. The NRC staff has determined that TerraPower's plan for V&V addresses the avoidance of bias in participant sampling and, therefore, concludes that criterion 11.4.3.4(4) is met.

10.3.5 Performance Measurement (Criteria 11.4.3.5.1 - 11.4.3.5.2)

10.3.5.1 Types of Performance Measures (Criteria 11.4.3.5.1(1)-(6))

10.3.5.1.1 Identification of Performance Measures (Criterion 11.4.3.5.1(1))

Criterion 11.4.3.5.1(1) states that the applicant should identify the specific plant performance measures applicable to each ISV scenario.

Section D.6.7 of the TR describes the performance measures used in ISV. **[[**

]] Two types of performance measures are stated to be used within ISV. **[[**

]] The second type are supplemental measures which provide validation information and support design refinement and enhancement. These supplemental measures include crew communication, crew coordination, situation awareness, physical workload, cognitive workload, ergonomics and physiological factors. The NRC staff has determined that TerraPower's plan for V&V addresses ISV scenario performance measures and, therefore, concludes that criterion 11.4.3.5.1(1) is met.

10.3.5.1.2 Identification of Primary Task Measures (Criterion 11.4.3.5.1(2))

Criterion 11.4.3.5.1(2) states that the applicant should identify the primary task measures applicable to each ISV scenario.

Section D.6.7 of the TR describes the performance measures used in ISV. Two types of performance measures are stated to be used within ISV, specifically decisive measures and

supplemental measures. **[[**
]]
Specifically, section D.6.7.1 of the TR states **[[**

]] Section D.6.7.2, “Plant-Safety Analysis and Probabilistic Risk Assessment,” of the TR states **[[**

]] Lastly, section D.6.7.3, “Personnel Tasks,” of the TR states **[[**

]]

The NRC staff has determined that TerraPower’s plan for V&V addresses the identification of primary task measures for ISV scenarios and, therefore, concludes that criterion 11.4.3.5.1(2) is met.

10.3.5.1.3 Identification of Secondary Task Measures (Criterion 11.4.3.5.1(3))

Criterion 11.4.3.5.1(3) states that the applicant should identify the secondary task measures applicable to each scenario. Section D.6.7 of the TR describes the performance measures used in ISV, which include supplemental measures. Supplemental measures are described as providing validation information and support design refinement and enhancement. These supplemental measures include crew communication, crew coordination, situation awareness, physical workload, cognitive workload, ergonomics and physiological factors.

Section D.6.7.4, “Crew Communication and Coordination,” of the TR states **[[**

]] Section D.6.7.5, “Situation Awareness,” of the TR states **[[**

. **]]** Section D.6.7.6, “Workload,” of the TR states
[[

]] Lastly, section D.6.7.7, “Ergonomic and Physiological Factors,” of the TR states that control room ergonomics are evaluated against anthropometric guidelines during HSI development and HFE DV, with significant ergonomic issues also being entered as HEDs in the HFEITS. The NRC staff has determined that TerraPower’s plan for V&V addresses the identification of secondary task measures for ISV scenarios and, therefore, concludes that criterion 11.4.3.5.1(3) is met.

10.3.5.1.4 Situational Awareness Measures (Criterion 11.4.3.5.1(4))

Criterion 11.4.3.5.1(4) states that the applicant should identify the measures of situation awareness applicable to each scenario. Section D.6.7.5 of the TR discusses how situational awareness is assessed during V&V activities. It is described that operators’ perceptions about situations, as they compare to reality, are tested in conjunction with scenarios as a means of assessing situation awareness. During early validation testing, section D.6.7.5 of the TR states that the situation awareness global assessment technique (SAGAT) is applied, in which simulations are periodically frozen, system displays are blanked out, and operators are questioned regarding their situational understanding.

Section D.6.7.5 of the TR further states that the SAGAT is only used during early validation testing and is also used along with the situation awareness rating technique (SART). SART is not used in isolation and assessment of situation awareness is augmented with behavior observations and performance measures. Furthermore, additional supplemental information is obtained using participant eye-movement tracking. Section D.6.7.5 of the TR states that the basis for this methodology is that "the use of mixed performance measures during early validation testing helps to establish concurrent validity of the SART and the supplemental performance measures as a means of assessing situation awareness relative to the SAGAT" while "assessment using mixed methods together enables the data analyst to more closely approximate the actual level of participant awareness and make an assessment regarding overall adequacy."

However, during subsequent ISV scenarios, section D.6.7.5 of the TR states that the simulation is not frozen and questions to measure situation awareness are instead administered following the completion of a scenario. The questions used are described as covering three different levels of situation awareness, specifically perception of data, comprehension of meaning, and projection of the future. D.6.7.5 of the TR further discusses that the assessment of situation awareness during ISV is also supplemented through observations, recordings of participant task performance, participant debriefing, and participant self-reflection of performance outcomes. Determinations regarding the acceptability of performance is determined by assessing the level of situation awareness in terms of both perception of data, comprehension of meaning, and projection of the future, with HEDs being entered into the HFEITS as warranted.

Based on the above, the NRC staff has determined that TerraPower's plan for V&V identifies the measures of situation awareness that will be applied during scenarios and, therefore, concludes that criterion 11.4.3.5.1(4) is met.

10.3.5.1.5 Workload Measures (Criterion 11.4.3.5.1(5))

Criterion 11.4.3.5.1(5) states that the applicant should identify the workload measures obtained for each scenario.

Section D.6.7.6 of the TR describes the methods that are used to assess both physical and cognitive workload during V&V. Test personnel use video recordings and observations to evaluate the effects of physical workload on performance, as well as to identify conditions involving forceful exertions, awkward postures, repetitiveness, vibration, or pressure points. Physical workload measures that exceed criteria (which are stated to be derived from both State of Washington Department of Labor and Industries and National Institute for Occupational Safety and Health guidelines) are documented as HEDs in the HFEITS. Section D.6.7.6 of the TR further discusses that workload is assessed as part of a cumulative evaluation process that occurs across the design lifecycle (versus only being assessed during the ISV). This is described as including assessment of workload by subject matter experts during both the AOF and TA, using platforms and mock-ups during HSI testing, using layout evaluation and procedure step-though during task support validation, and, lastly, through the confirmatory workload assessment of the ISV.

Section D.6.7.6 of the TR states that cognitive workload is measured during ISV by the NASA-TLX. The tasks and event sequences that make up these ISV scenarios include workload conditions with high error potential, operator burdens, or time pressures. The NASA-TLX approach consists of a subjective measurement of workload that uses post-scenario participant questionaries to assess six dimensions of mental workload-related factors (i.e., mental demand, physical demand, temporal demand, performance, effort, and frustration). Weighting factors are the applied to develop an overall measure of cognitive workload. **[[**
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Section D.6.7.6.2, "Cognitive Workload," of the TR describes that cognitive workload is assessed in an integrated manner to offset the subjective nature of self-report data and allow "…HFE analysts to triangulate cognitive workload using a combination of mixed methods, providing a more comprehensive assessment of cognitive workload." These methods are described as including assessing cognitive workload in relation to situation awareness, supplementing the assessment of cognitive workload through observations of performance (e.g., reaction times, number of errors, and task completion times), and using eye-movement tracking to provide insights into cognitive load.

Based on the above, the NRC staff has determined that TerraPower's plan for V&V identifies the workload measures that will be utilized during scenarios and, therefore, concludes that criterion 11.4.3.5.1(5) is met.

10.3.5.1.6 Anthropometric and Physiological Measures (Criterion 11.4.3.5.1(6))

Criterion 11.4.3.5.1(6) states that the applicant should identify the anthropometric and physiological measures obtained for each scenario.

Section D.6.7.7 of the TR states that MCR ergonomics are evaluated against the anthropometric data of the HSI style guide during HFE DV, with both system-specific and integrated validation testing being utilized to confirm the adequacy of the HSI ergonomic design during simulation. A set of physical measurement (e.g., stature, seat height, eye height, span, hand length, etc.) are taken for the ISV testing participants, which are used in conjunction with observations and self-reporting to identify ergonomic issues. Evaluation of anthropometric and ergonomic data is described as occurring using ergonomic guidelines, expert judgement, and the HFE DRD. Ergonomic design issues related to MCR layout and HSIs that result in procedures not being correctly accomplished within time constraints result in ISV failures. Additionally, any identified risks to operator safety result in HEDs being entered into the HFEITS. The NRC staff has determined that TerraPower's plan for V&V addresses the identification of the anthropometric and physiological measures to be obtained during ISV and, therefore, concludes that criterion 11.4.3.5.1(6) is met.

10.3.5.2 Performance Measure Information and Validation Criteria (Criteria 11.4.3.5.2(1)-(5))

Criteria 11.4.3.5.2(1) – (5) state that the applicant should describe (1) the methods by which performance measures are obtained, (2) when each measure is obtained (recorded), (3) the characteristics of the performance measures, (4) the specific criterion for each measure used to judge the acceptability of performance and describe its basis, and (5) whether each measure is a pass/fail one or a diagnostic one.

Section D.6.7 of the TR describes the HFE validation performance measures that are used to assess the adequacy of the integrated system, which include the following: core thermal-hydraulic condition, safety analysis and probabilistic risk assessment, personnel tasks, crew communication and coordination, situation awareness, workload, and ergonomic and physiological factors. The methods by which the performance measures are obtained vary according to the measure involved and include, in part, observations, simulator data, tests, and questionnaires. The description provided for these measures includes when they are obtained, such as before, during, or after ISV scenarios. Additionally, relevant characteristics of these performance measures (e.g., construct validity, sensitivity, and objectivity) are addressed by the descriptions provided within this section of the HFEPP. For performance measures, the specific criteria used to assess acceptability, as well their underlying bases (e.g., performance requirements or expert judgement), are generally addressed. Lastly, two distinct types of performance measures are stated as being used within ISV, specifically decisive measures (i.e., pass/fail measures) and supplemental measures (i.e., those providing validation information and supporting design refinement and enhancement). The NRC staff has determined that TerraPower's plan for V&V addresses appropriate performance measure information and, therefore, concludes that criteria 11.4.3.5.2(1) – (5) are met.

10.3.6 Test Design (Criteria 11.4.3.6.1 - 11.4.3.6.5)

10.3.6.1 Scenario Sequencing (Criteria 11.4.3.6.1(1)-(2))

10.3.6.1.1 Balance of Scenario Range (Criterion 11.4.3.6.1(1))

Criterion 11.4.3.6.1(1) states that the applicant should balance scenarios across crews to provide each crew with a similar, representative range of scenarios. Section D.6.8, "Test Design," of the TR states that the ISV test design process addresses the avoidance of bias in scenario assignments and test personnel qualifications. Section D.6.8.1, "Scenario Assignment," of the TR discusses **[[**

]] The NRC staff has determined that TerraPower's plan for V&V addresses the balancing of scenarios across crews and, therefore, concludes that criterion 11.4.3.6.1(1) is met.

10.3.6.1.2 Balance of Scenario Order (Criteria 11.4.3.6.1(2))

Criterion 11.4.3.6.1(2) states that the applicant should balance the order of presentation of scenarios to crews to provide reasonable assurance that the scenarios are not always presented in the same sequence. Section D.6.8.2, "Scenario Sequencing," of the TR discusses **[[**

]] The NRC staff has determined that TerraPower's plan for V&V addresses the balanced ordering of scenario presentation and, therefore, concludes that criterion 11.4.3.6.1(2) is met.

10.3.6.2 Test Procedures (Criteria 11.4.3.6.2(1)-(2))

10.3.6.2.1 Use of Procedures (Criterion 11.4.3.6.2(1))

Criterion 11.4.3.6.2(1) states that the applicant should use detailed, unambiguous procedures to govern the conduct of the tests. These procedures should include identifying which scenarios that crews receive, the order that scenarios should be presented in, directions for the personnel conducting tests, guidance for addressing testing difficulties, data collection instructions, and documentation procedures. Section D.6.8 of the TR describes, **[[**

]] The NRC staff notes that the processes described by the HFEPP for these areas should reasonably lead to adequate procedures when they are fully developed prior to ISV implementation. The NRC staff has determined that TerraPower's plan for V&V addresses processes and procedures to govern the conduct of the tests and, therefore, concludes that criterion 11.4.3.6.2(1) is met.

10.3.6.2.2 Avoidance of Bias (Criterion 11.4.3.6.2(2))

Criterion 11.4.3.6.2(2) states that the applicant's test procedures should minimize the opportunity for bias in the test personnels' expectations and in the participant's responses.

Section D.6.8.2 of the TR states **[[**

]] Section D.6.8.3, "Test Steps," of the TR describes **[[**

]] Additionally, section D.6.10.3, "Controlling for Bias," of the TR discusses **[[**

]] The NRC staff has determined that TerraPower's plan for V&V addresses measures to minimize the opportunity for bias and, therefore, concludes that criterion 11.4.3.6.2(2) is met.

10.3.6.3 Test Personnel Training (Criterion 11.4.3.6.3(1))

Criterion 11.4.3.6.3(1) states that the applicant should train test personnel (those who conduct or administer the validation tests) on the use and importance of test procedures, bias and errors that test personnel may introduce into the data through failures to either follow test procedures accurately or interact with participants properly, and the importance of accurately documenting problems arising during testing (even if they were due to an oversight or error by those conducting the test). Section D.6.8.9 of the TR states that prior to the beginning of ISV, test personnel will complete training that is comparable to that of simulator instructors/evaluators. The scope of this training is described as including, in part, the usage and importance of test procedures, the potential errors and biases that can be introduced by not properly interacting with test participants or adhering to procedures, and the importance of documenting testing problems irrespective of whether test personnel themselves caused them. The NRC staff has determined that TerraPower's plan for V&V appropriately addresses the training of test personnel and, therefore, concludes that criterion 11.4.3.6.3(1) is met.

10.3.6.4 Participant Training (Criteria 11.4.3.6.4(1)-(2))

10.3.6.4.1 Training of Participants (Criterion 11.4.3.6.4(1))

Criterion 11.4.3.6.4(1) states that the applicant's training of participants should be very similar to the training plant personnel receive.

Section D.6.8.10, "Test Participants Training and Requisites," of the TR states that comprehensive knowledge of the systems included in the ISV testing is attained by means of a combination of classroom and simulator training. ISV test participants that were previously licensed at a nuclear power plants will complete Natrium-specific systems training, procedure training and simulator training. Additionally, training on generic fundamentals is provided for test participants who lack previous nuclear power plant OE. This training program is described as culminating with both a comprehensive examination and systems job performance measures using the simulator. Test participants are administered a comprehensive operating test using a full-scope simulator prior to participating in full-scope simulator V&V testing. The NRC staff notes that the scope, format, content, and assessment methods described for the training of ISV participants generally parallel those that would be expected for licensed operators. The NRC staff has determined that TerraPower's plan for V&V addresses the training of ISV participants to a similar degree as that which would be expected for plant personnel and, therefore, concludes that criterion 11.4.3.6.4(1) is met.

10.3.6.4.2 Representative participant performance (Criterion 11.4.3.6.4(2))

Criterion 11.4.3.6.4(2) states that to assure that the participants' performance is representative of plant personnel, the applicant's training of participants should result in near asymptotic performance (i.e., stable, not significantly changing from trial to trial) and should be tested for such before conducting the validation. Section D.6.8.10 of the TR states that ISV test participants will have been trained sufficiently for them to demonstrate acceptably stable performance across trials. Additionally, it further states that ISV test participants are administered a comprehensive operating test using a full-scope simulator prior to participating in full-scope simulator V&V testing. The NRC staff has determined that TerraPower's plan for V&V addresses the establishment of stable test participant performance and, therefore, concludes that criterion 11.4.3.6.4(2) is met.

10.3.6.5 Pilot Testing (Criteria 11.4.3.6.5(1)-(2))

10.3.6.5.1 Conduct of Pilot Study (Criterion 11.4.3.6.5(1))

Criterion 11.4.3.6.5(1) states that the applicant should conduct a pilot study before the validation tests begin to offer an opportunity for the applicant to assess the adequacy of the test design, performance measures, and data collection methods. Section D.6.9, "Pilot Testing," of the TR states that a pilot study is to be conducted before V&V occurs in the simulator, including the running of the future ISV scenarios in advance of the actual ISV testing. Section D.6.9 of the TR states that the pilot study tests the processes used to evaluate design adequacy, determines appropriate data collection techniques, and verifies completeness and fidelity of the testbed. **[[**

]] The NRC staff has determined that TerraPower's plan for V&V addresses the conduct of a pilot study in advance of validation and, therefore, concludes that criterion 11.4.3.6.5(1) is met.

10.3.6.5.2 Selection of Pilot Participants (Criterion 11.4.3.6.5(2))

Criterion 11.4.3.6.5(2) states that the applicant should not use participants in the pilot testing who will then be participants in the validation tests. Section D.6.9 of the TR states that personnel who fill the roles of crew members during pilot testing will not be later utilized as test participants during the ISV. Participants in the pilot testing are instead described as subsequently filling roles as test personnel during ISV (which is distinct from serving as participants) due to their familiarity with the tests that will be performed. The NRC staff has determined that TerraPower's plan for V&V addresses the selection of appropriate participants for pilot testing and, therefore, concludes that criterion 11.4.3.6.5(2) is met.

10.3.7 Data Analysis and HED Identification (Criteria 11.4.3.7(1)-(7))

10.3.7.1 Use of Quantitative and Qualitative Methods (Criterion 11.4.3.7(1)) and Method of Data Analysis (Criterion 11.4.3.7(2))

Criterion 11.4.3.7(1) states that the applicant should use a combination of quantitative and qualitative methods to analyze data. Criterion 11.4.3.7(2) states that the applicant should discuss the method by which data is analyzed across trials, and include the criteria used to determine successful performance for a given scenario.

Section D.6.10, "Data Analysis," of the TR describes that data analysis is structured around a four-tier hierarchical set of performance measures, with the analyses depending on the type of associated data. **[[**

]] Furthermore, section D.6.10 of the TR states that test participant observations are collected to facilitate qualitative assessments factors such as lighting and noise levels.

The NRC staff notes that the combination of data analyses presented in section D.6.10 encompasses both quantitative analysis (e.g., assessment of whether core thermal limits were met or whether tasks were completed within required times) as well as qualitative analysis (e.g., communications and noise-related issues). The NRC staff has determined TerraPower's plan for V&V addresses the use of an appropriate combination of methods to analyze data, as well as how data is analyzed to determine successful scenario performance and, therefore, concludes that criteria 11.4.3.7(1) – (2) are met.

10.3.7.2 Degree of Convergence Between Measures (Criterion 11.4.3.7(3))

Criterion 11.4.3.7(3) states that the applicant should evaluate the degree of convergence between related measures (i.e., consistency between measures expected to assess the same aspect of performance). Section D.6.10.2, “Establishing Convergent Validity,” of the TR discusses that convergent validity is determined during data analysis by comparing data across performance measures that are intended to measure similar performance aspects. **[[**

]] Section D.6.10.2 of the TR also states that HEDs will be entered into the HFEITS to document any instances where performance measures that intended to measure the same thing lack correlation. The NRC staff has determined that TerraPower’s plan for V&V addresses convergence between related measures and, therefore, concludes that criterion 11.4.3.7(3) is met.

10.3.7.3 Interpretation of Test Results (Criterion 11.4.3.7(4))

Criterion 11.4.3.7(4) states that when interpreting test results, the applicant should allow a margin of error to reflect the fact that actual performance may be slightly more variable than observed validation-test performance. Section D.6.10 of the TR describes that test personnel will consider that actual performance can be more variable than observed validation test performance and will account for this when drawing inferences and making generalizations between observed test performance and estimated real-world performance. The NRC staff has determined that TerraPower’s plan for V&V addresses the potential for actual performance to be more variable than test performance and, therefore, concludes that criterion 11.4.3.7(4) is met.

10.3.7.4 Correctness of Data Analysis (Criterion 11.4.3.7(5))

Criterion 11.4.3.7(5) states that the applicant should verify the correctness of the analyses of the data and also that this verification should be done by individuals or groups other than those who performed the original analysis. Section D.6.10.1, “Data Verification,” of the TR states that “Data analysis and the conclusions drawn are independently verified.” The NRC staff has determined that TerraPower’s plan for V&V addresses the independent verification of analyses and, therefore, concludes that criterion 11.4.3.7(5) is met.

10.3.7.5 Identification of HEDs (Criterion 11.4.3.7(6))

Criterion 11.4.3.7(6) states that the applicant should identify HEDs when the observed performance does not meet the performance criteria. Multiple subsections within section D.6 of the TR discuss the documentation of HEDs during ISV, with deficiencies and discrepancies that are identified during V&V activities being entered into the HFEITS as HEDs. Examples of the various instances in which the HFEPP addresses the identification of HEDs during ISV include, in part, the following:

- occurrences of significant sampling bias;
- tasks resulting in failures of a crew to meet acceptance criteria;
- performance concerns identified in supplemental measurement areas;
- physical workload occurrences that exceed criteria;
- instances where two performance measures that are intended to measure the same thing lack correlation;
- determinations that an ISV test must be completed using the plant instead;

- **[[**

  ]]
- HSI ergonomics that represent a risk to operator safety or well-being; or
- performance on a performance measure which only passes the related acceptance criteria by a small margin.

The NRC staff has determined that TerraPower's plan for V&V addresses the identification of HEDs during ISV and, therefore, concludes that criterion 11.4.3.7(6) is met.

10.3.7.6 Resolution of HEDs (Criterion 11.4.3.7(7))

Criterion 11.4.3.7(7) states that the applicant should resolve HEDs identified bypass/fail measures before the design is accepted. Section D.6.7 of the TR discusses the performance measures used in ISV, which include decisive measures. **[[**

]] Section D.6.10 of the TR states that, "[F]or performance measures used as pass/fail indicators, failed indicators are resolved before the design is validated." The NRC staff has determined that TerraPower's plan for V&V addresses the resolution of those HEDs identified bypass/fail measures prior to design acceptance and, therefore, concludes that criterion 11.4.3.7(7) is met.

10.3.8 Validation Conclusions (Criteria 11.4.3.8(1)-(2))

10.3.8.1 Documentation of Bases for Acceptability (Criterion 11.4.3.8(1))

Criterion 11.4.3.8(1) states that the applicant should document the statistical and logical bases for determining that performance of the integrated system is, and will be, acceptable. Section D.6.11 of the TR states that the bases for acceptable performance and conclusions developed from validation will be documented. Section D.8 discusses that the results from ISV are documented afterwards in a results report. The NRC staff has determined that TerraPower's plan for V&V addresses documentation of the bases for ISV acceptability and, therefore, concludes that criterion 11.4.3.8(1) is met.

10.3.8.2 Documentation of Limitations (Criterion 11.4.3.8(2))

Criterion 11.4.3.8(2) states that the applicant should document the limitations in the validation tests, their possible effects on the conclusions of the validation, and their impact on implementing the design. Section D.6.11, "Human Factors Validation Outputs," of the TR states that validation testing limitations, as well as how these limitations might affect validation conclusions or design implementation, will be documented. Several examples of these potential issues are discussed, including testing aspects that were not well controlled, differences between testing and actual operating situations, and differences between the design that was validated and the actual as-built design. The NRC staff has determined that TerraPower's plan for V&V addresses the potential effects of validation testing limitations and, therefore, concludes that criterion 11.4.3.8(2) is met.

10.4 <u>Human Engineering Discrepancy Resolution (Criteria 11.4.4(1)-(5))</u>

Criteria 11.4.4(1) – (5) state that the applicant should (1) include an adequate scope within the HED analyses (i.e., personnel tasks and functions, plant systems, cumulative effects of HEDs, and HEDs as indications of broader issues), (2) conduct an evaluation to identify which HEDs to correct, (3) identify design solutions to correct HEDs, (4) evaluate design solutions to demonstrate the resolution of that HED and ensure that new HEDs are not introduced, and (5) document each HED (including the basis for not correcting an HED, related personnel tasks and functions, related plant systems, cumulative effects of HEDs, and HEDs as indications of broader issues).

Section 5.10 of the TR states that V&V plan includes the identification, documentation, prioritization, analysis, and resolution of HEDs. Section 8 of the TR describes the overall processes associated with the identification and resolution of HEDs. HEDs are documented and tracked for dispositioning in the HFEITS. Section 5.6 of the TR states **[[** **]]** Section 8.1 of the TR also describes that HEDs are documented, in part, when deviations from HF DRD requirements are identified or when an HSI does not meet information and control requirements that were established by the TA.

Section 8.3, “Human Engineering Discrepancy Cumulative Effects Analysis,” of the TR discusses the analysis of the cumulative effects of HEDs, which includes grouping HEDs such that their combined effects and interactions are understood. Section D.6, “Human Factors Engineering Validation,” of the TR discusses **[[** **]]** Section 8.2 of the TR describes the prioritization of HEDs according to a three-leveled approach with priority 1 representing “highest” priority (i.e., involving safety consequences), priority 2 representing high priority (i.e., involving plant or personnel performance effects), and Priority 3 representing low priority (i.e., enhancements). Section 8.4 of the TR describes the process for determining the adequacy of a revised design, the processes and HFE methods by which HEDs will be retested as part of their resolution, as well as the process by which HEDs may, with an acceptable basis, be justified and closed. The NRC staff has determined that TerraPower’s plan for V&V addresses HED analysis, selection of HEDs to correct, development and evaluation of design solutions, and the documentation of HED evaluations. Therefore, the NRC staff concludes that criteria 11.4.4(1) – (5) are met.

10.5 Overall Conclusion for the V&V Element

The NRC staff concludes that TerraPower’s plan for V&V, as described by the TR, is generally consistent with the relevant criteria of NUREG-0711. The associated results of this plan’s implementation can be reviewed by the NRC staff when a future V&V RSR has been provided.

11.0 DESIGN IMPLEMENTATION

The NRC staff’s objective in the review of this element is to verify the adequacy of the applicant’s processes for ensuring that the as-built design will conform to the verified and validated design that resulted from the HFE design process. The NRC staff evaluated the HFEPP using the relevant review criteria in NUREG-0711, section 12.4, “Review Criteria,” and the results of the NRC staff’s evaluation are discussed below in section 11.1. It should be noted that, per NUREG-0711, an associated RSR is expected for this element, however, RSRs are not included as part of this HFEPP and will need to be submitted and reviewed as part of an OLA.

11.1 Final Verification of the HFE Design

NUREG-0711 provides four criteria for the design implementation element (i.e., criteria 12.4.1(1-4)) which address whether (1) an applicant evaluates aspects of the design that were not addressed in V&V by an appropriate V&V method, (2) compares the final HSIs, procedures, and training with the detailed description of the design to verify that they conform to the planned design resulting from the HFE design process and V&V activities, (3) verifies that all HFE-related issues in the issue tracking system are adequately addressed, and (4) provides a description of how the HFE program addressed each important HA.

Section 5.11, "Design Implementation," of the TR presents a high-level list of activities to be conducted during design implementation and states that the detailed methodology will be developed in a HF design implementation methodology plan. The NRC staff notes that the described activities include the following:

- Verification of aspects of the design not previously evaluated in the V&V process. It is stated that the scope of this verification includes hardware, software, and new/modified displays that were not included in the simulator-based ISV. Additionally, it is described that physical and environmental differences between those aspects present during V&V activities and those reflected in the as-built facility (such as, for example, lighting and noise considerations) will be verified as well.

- Verification that the as-built HSIs, procedures, and training are consistent with those resulting from HFE design and V&V activities. Additionally, it is stated that any deviations from the design and their HFE effects will be evaluated as part of the design implementation process.

- Verification of the resolution of open items from HFEITS, as well as remaining HEDs.

- **[[**

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Based on the above, the NRC staff has determined that TerraPower's plan for design implementation addresses 1) aspects of the as-built design that were not addressed during V&V activities, 2) verifying that HSIs, procedures, and training conform to the planned design, 3) the resolution of HFE-related issues in the issue tracking system, and 4) the HFE treatment on important HAs. Therefore, the NRC staff concludes that criteria 12.4.1(1) – (4) are met.

11.2 Overall Conclusion for the Design Implementation Element

The NRC staff concludes that TerraPower's plan for design implementation, as described by the TR, is generally consistent with the relevant criteria of NUREG-0711. The associated results of this plan's implementation can be reviewed by the NRC staff when a future design implementation RSR has been provided.

12.0 HUMAN PERFORMANCE MONITORING

The NRC staff's objective in the review of this element is to verify that the applicant has prepared a human performance monitoring strategy for ensuring that no significant safety degradation occurs because of any changes that are made in the plant and to verify that the conclusions that have been drawn from the human performance evaluation remain valid over the life of the plant. The NRC staff evaluated the TR using the relevant review criteria in NUREG-0711, section 13.4, "Review Criteria," and the results of the NRC staff's evaluation are discussed below in section 12.1. It should be noted that, per NUREG-0711, there is no associated RSR expected for this element.

12.1 Program Scope, Development, Structure, Use of Approximations, and Corrective Actions (Criteria 13.4(1) – (5))

Criterion 13.4(1) states that the scope of the applicant's performance monitoring program should provide reasonable assurance that personnel can use the design effectively, changes do not adversely affect human performance, important HAs can be accomplished within the criteria for time and performance, and that an acceptable level of performance is maintained. Criterion 13.4(2) states that the applicant should develop and document a human performance monitoring program which should be able to 1) trend human performance after the plant is operational, or after modifications were made to demonstrate that performance is consistent with that assumed in the various analyses that were conducted to justify the change and 2) begin at initial loading of the plant's fuel. Criterion 13.4(3) states that the applicant should structure the program such that the level of monitoring for human actions is commensurate with their safety importance, feedback of information and corrective actions are accomplished in a timely manner, and degradations in performance can be detected and corrected before they compromise plant safety. Criterion 13.4(4) states that the applicant should use approximations of performance data when the performance of the plant or personnel under actual design basis conditions may not be readily measurable. Finally, criterion 13.4(5) states that the applicant should include, within the program, provisions for determining the specific cause of performance degradation and failures, undertaking corrective actions, and trending them.

Section 5.12, "Human Performance Monitoring," of the TR states that human performance monitoring will be performed by the operating entity throughout the operational phase of the plant and that metrics of human performance will be tracked 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 is described as detailing the process for detecting performance degradations and providing HF solutions. During the audit, TerraPower clarified that the aspects of the human performance monitoring element that are covered by this criterion are outside of the scope of the TR and that a future report will be provided in conjunction with OLA that addresses these items.

The NRC staff concludes that review of TerraPower's plan for human performance monitoring can be deferred until review of an OLA. This represents an incomplete aspect of the NUREG-0711 review methodology that is addressed in the "Limitations and Conditions" section of this evaluation.

LIMITATIONS AND CONDITIONS

The NRC staff identified the following limitations and conditions, applicable to any licensee or applicant referencing this TR:

1. Applicants or licensees referencing this TR must make the RSRs associated with the following HFE elements available to support staff review of an OLA:

    a. Operating experience review
    b. Functional requirements analysis and function allocation
    c. Task analysis
    d. Staffing and qualifications
    e. Treatment of important human actions
    f. Human-system interface design
    g. Verification and validation
    h. Design implementation

2. Applicants or licensees referencing this TR must provide a schedule of HFE tasks, consistent with criteria 2.4.3(4) and 2.4.5(2) of NUREG-0711, to facilitate staff reviews of HFE submittals associated with applications for facility licensing. Additionally, the status of HFE activities will need to be provided, consistent with criterion 2.4.5(1).

3. To address the “Staffing and Qualification” element of NUREG-0711 section 6, operating license (OL) applicants referencing this TR must provide sufficient information to meet the relevant criteria in NUREG-0800, chapters 13.1.1 and 13.1.2 – 13.1.3, consistent with the guidance and related criteria of DANU-ISG-2022-05.

4. Applicants or licensees referencing this TR must either address STA staffing or provide an adequate justification to the NRC staff to support the omission of the STA from the staffing model, as well as any associated exemption request(s).

5. To address NUREG-0711, sections 8.4.4.3 and 8.4.4.4, OL applicants referencing this TR must provide information sufficient to demonstrate how the relevant criteria of these sections will be met by the emergency facilities that are included in the emergency plan.

6. To address the “Procedure Development” element of NUREG-0711, section 9, OL applicants referencing this TR must provide information sufficient to meet the relevant criteria NUREG-0800, sections 13.5.1.1, and 13.5.2.1 consistent with the guidance and related criteria of DANU-ISG-2022-05.

7. To address the “Training Program Development” element of NUREG-0711, section 10, OL applicants referencing this TR must provide information sufficient to meet the guidance and related criteria DANU-ISG-2022-05 for licensed operator initial training, licensed operator requalification training, and non-licensed plant staff training (including the specific categories of personnel to be trained under the SAT-based training programs).

8. Applicants or licensees referencing this TR must provide a plan for human performance monitoring that is adequate to meet the criteria of NUREG-0711, section 13.

9. Applicants or licensees referencing this TR outside the context of a Licensing Modernization Project (LMP) based approach must describe how the TR remains applicable outside of an LMP-based context and, as appropriate, supplement the TR as needed.

10. Applicants or licensees referencing this TR without also incorporating NATD-LIC-RPRT-0001-A, Revision 0 "Regulatory Management of Natrium Nuclear Island and Energy Island Design Interfaces," (ML24011A321) must describe how this TR remains applicable in light of any differences and, as appropriate, supplement this TR as needed.

CONCLUSION

The NRC staff has determined that, subject to the limitations and conditions contained in this evaluation, the HFEPP described within the TR presents an overall methodology that is generally consistent with a state-of-the-art approach to HFE, as described by NUREG-0711. The HFEPP presents plans associated with the various elements of the Natrium HFE program. The NRC staff concludes that these plans are adequate to address the related HFE elements and should reasonably lead to the development of a design that incorporates appropriate HFE principles. However, as the HFEPP only represents the IPs for these HFE elements, the NRC staff further has determined that a making subsequent finding on the overall HFE acceptability of a design produced via implementation of the HFEPP will require future staff review of both the information contained in the RSRs from implementation of the relevant elements of the HFEPP, as well as of the associated OLA.

ACRONYMS

AOF	allocation of function
AOP	abnormal operating procedures
COO	concept of operations
D3	diversity and defense-in-depth
DRD	design requirements document
DV	design verification
EI	energy island
EOF	emergency operations facility
EOP	emergency operating procedures
FRA	functional requirement analysis
FA	function allocation
GTG	generic technical guidelines
HA	human action
HEDs	human engineering discrepancies
HEFITS	human factors engineering issue tracking system
HF	human factors
HFE	human factors engineering
HFEPP	human factors engineering project plan
HSI	human-system interface
HRA	human reliability analysis
I&C	instrumentation and control
IEC	International Electrotechnical Commission
IHAs	important human actions
IP	implementation plan

IEEE	Institute of Electrical and Electronics Engineers
ISV	integrated system validation
JPM	job performance measure
LCS	local control station
MCR	main control room
NASA-TLX	National Aeronautics and Space Administration-Task Load Index
NI	nuclear island
OE	operating experience
OER	operating experience review
OL	operating license
OLA	operating license application
PDP	procedure development plan
PRA	probabilistic risk analysis
RSC	remote shutdown complex
RSR	results summary report
SAGAT	situational awareness global assessment technique
SART	situational awareness rating technique
SAT	systems approach to training
SPDS	safety parameter display system
SRO	senior reactor operator
SSC	structure, system, and components
STA	shift technical advisor position
TA	task analysis
TIHA	treatment of important human actions
TMI	Three Mile Island
TR	topical report
TSC	technical support center
TPDP	training program development plan
TSV	task support verification
V&V	verification and validation

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REVISION HISTORY

Revision No.	Affected Section(s)	Description of Change(s)
0	All	Initial Issue.
1	Sections 1, 4, 5, 6, 8, C and D	Updates to affected sections based on responses to NRC audit questions. Updates to acronyms, acronym table, and references.

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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
EI	Energy Island
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

Acronym	Definition
NEA	Nuclear Energy Agency
NI	Nuclear Island
NIOSH	National Institute for Occupational Safety and Health
NRC	Nuclear Regulatory Commission
MCR	Main Control Room
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
RSC	Remote Shutdown Complex
RSR	Result Summary Report
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™ 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

[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:

- Main Control Room (MCR)
- Remote Shutdown Complex (RSC)
- Local controls
- Emergency support facilities

Remote control and monitoring of NI and Energy Island (EI) equipment is performed from workstations in the MCR, however, the EI is not included in the scope of the HFEPP. The EI was not included in the scope of the HFEPP because no EI SSCs are required to (1) respond to mitigate any events impacting the NI, (2) support safety-related SSCs, or (3) ensure defense-in-depth adequacy.

The overall layout and interface of the NI and EI workstations is performed as part of integrated MCR design, with the workstations being of the same general design. This allows both to benefit from the NI workstation ergonomic design and evaluation.

Additionally, the MCR EI interface will include any necessary features or operational protocols to prevent NI operating staff from having their workload or situational awareness adversely impacted by EI operations. The MCR EI interface will be tested to be satisfactory with MCR Testing and Evaluation (T&E) and Integrated System Validation (ISV).

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.

1.3 Assumptions and Constraints

The initial staffing assumption aligns with the staffing requirements in Title 10 of the Code of Federal Regulations (10 CFR) Part 50, “Domestic Licensing of Production and Utilization Facilities,” Section 54, “Conditions of licenses,” (Reference 1), paragraph (m). This assumption is confirmed through the staffing analysis included in Appendix C.

There have been no additional assumptions identified that apply to the overall HFE program. There are assumptions made during design when inputs are not available or confirmed. These assumptions are later confirmed with the design and testing program. There have been no constraints identified that apply to the general HFE program.

1.4 Duration

The HFE program will be in effect from the start of the conceptual design cycle through completion of the initial plant startup test program, with the Human Performance Monitoring Program specified and active before initial fuel loading.

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 2), 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 3), and NUREG-0711 (Reference 4).

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 5) 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 6). 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 4).

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 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

i. Provide knowledge of the processes involved in controlling reactivity and generating power

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.

4.1.3 Organizational Placement

The HFE Technical Lead coordinates design activities with the TerraPower HFE Program Owner who provides the oversight function. The TerraPower HFE Program Owner is responsible for ensuring that the communication, reporting, and processing of HFE concerns is advocated and resolved through the TerraPower design organization.

The TerraPower HFE Program Owner reports to a Senior Manager responsible for the HFE Program. The Senior Manager responsible for the HFE Program is the control account manager, technical design authority, and senior level advocate for HFE.

The individuals or specific reporting relationships are subject to change, however the HFE program will have senior management representation and design authority through a TerraPower Senior Manager. The TerraPower organization will use established processes and procedures to identify, understand, and resolve issues relating to the HFE scope.

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 4). The actual engineering design team disciplines may vary, but the scopes described are covered. The qualification and experience requirements for the individuals supporting as extended members of the HFE team are determined by the performer’s quality program and related procedures. Plant Procedures and Personnel Training are developed in accordance with the licensee’s administrative procedures; therefore, these roles are not summarized herein.

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. MCR
    b. RSC
    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.

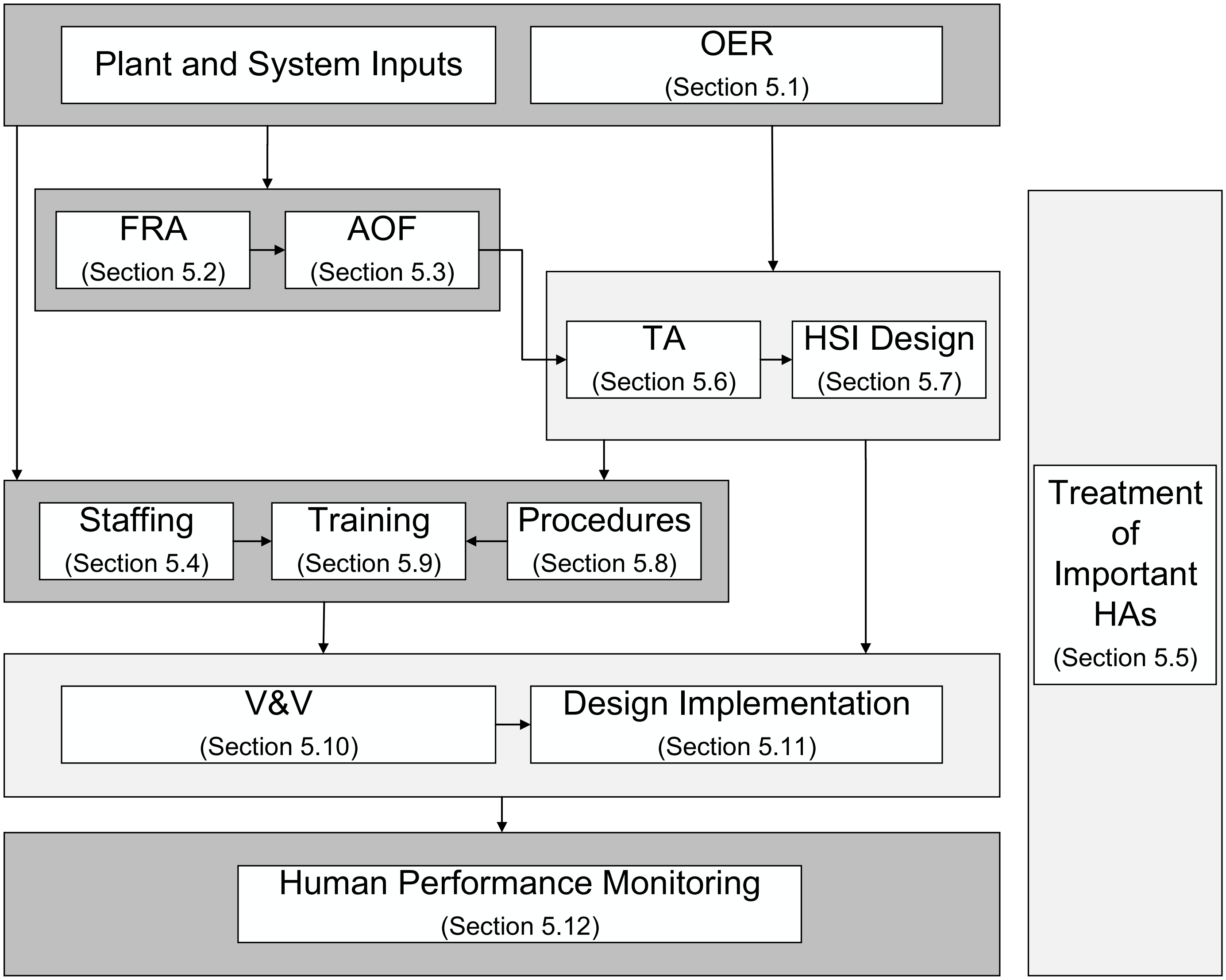

Figure 5-1: Human Factors Engineering Technical Elements Relationship

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
- HFE issues identified in NUREG/CR-6400, Human Factors Engineering (HFE) Insights for Advanced Reactors Based Upon Operating Experience (Reference 7)

Outputs of the OER may influence the design or design processes in each of the other HFE technical elements. Operating experience issues relevant to the HFE design but not yet addressed are documented in the Human Factors Engineering Issue Tracking System (HFEITS) (Section 6.4).

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 includes a defense-in-depth methodology that establishes defense line functions with the independence necessary to assure safety adequacy in light of failures and degradations. This includes any diversity needed in control and instrumentation. The PRA provides input to this process. Some of the defense line functions are specified as manual human actions. The appropriateness of the manual human action is confirmed through the AOF process as provided in Section 5.3. 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 8). 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 9). 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 8) and INL/EXT-13-30117 (Reference 10), 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 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 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 11). 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 12)). 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).

The scope of a “Style Guide” is covered within the HFE DRD and the HSI Style Specification.

The HFE DRD and HFE design documents are developed to comply with codes, standards, and HFE best practices, such as NUREG-0700 (Reference 13) and MIL-STD-1472 (Reference 14). 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.

HFE design requirements are contained within a hierarchical document structure, with the HFE DRD being the high-level “bucket” document in which the project-applicable set of HFE design requirements are derived and contained. The HSI Style Specification contains the lower tier, implementation level design requirements for the design of both hardware-based panel design and software-based display design. Bases for the requirements in the HSI Style Specification are traceable back to the HFE DRD.

The HFE DRD or DRD source requirements and the Style Specification are flowed down to NI HSI contractor suppliers through the procurement process. This arrangement promotes a consistent look and feel across like HSIs in the MCR, RSC, and local control stations. Where there are commercial-off-the-shelf considerations for applied HSI designs and compliance with the HFE DRD or Style Specification, HFE evaluates and collaborates with the designer to develop a solution, or a justification of acceptability as provided in Section 5.7.5.

Implementation of HFE requirements by suppliers is confirmed through the V&V process described in Section 5.10.

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 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. Specification of design details to be implemented by a vendor will be provided in a User Interface Specification (UIS) developed as described in Section B.3. The final MCR design will provide indications that meet the technologically relevant aspects of 10 CFR 50.34 (Reference 2) paragraphs (f)(2)(iv), (v), (xi), (xvii), (xviii), (xix), (xxvi), and (xxvii).

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 or Style Specification, 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 15). 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.

[[

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

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

[[

]][(a)(4)]

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 16).

The HSIs in the MCR are designed to support the use of computer-based procedures. Storage space is provided in the MCR and the RSC for hardcopy sets of operating procedures to support required operation.

The procedures developed by this HFE technical element are used for ISV, as described in Section 5.10. Following ISV, the procedures are used 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 17), which endorses American National Standards Institute (ANSI) /American Nuclear Society (ANS)-3.1-2014 (Reference 18), with certain exceptions and clarifications listed in the Regulatory Position of Reference 17.

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 19).

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 4). In addition, the HF V&V plan includes relevant good practices provided in NUREG/CR-6393 (Reference 20), International Electrotechnical Commission (IEC) 61771:1995 (Reference 21), and IEEE 845-1999 (Reference 15).

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 procedures supporting TP-QA-PD-0001, TerraPower QA Program Description (Reference 22). These procedures include the processes for design and project decisions inclusive of HFE. The procedures also address the design change control process and the acceptance of engineering products from suppliers.

Companies supporting Natrium HFE perform work under their respective programs, plans, and procedures. For HFE work performed by GE Hitachi, these procedures are governed by NEDO-11209-A, GE Hitachi Nuclear Energy Quality Assurance Program Description (Reference 23). This includes procedures for design, review, and retention of engineering products. There are supporting procedures for workforce planning and scheduling and project management. Further, there are also supporting procedures addressing personnel qualification and technical training and proficiency that support making resource assignments.

The 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.

6.5 Results

Result Summary Reports (RSRs) will be developed addressing at least the minimum information stipulated in NUREG-0711 (Reference 4). The RSRs and supporting documentation will be created and retained as required by the performer's quality assurance program discussed in Section 6.1. TerraPower will provide the RSRs for NRC staff review.

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 Human Engineering Discrepancy Dispositioning and Documentation

All HEDs are dispositioned through correction, justification, or deferment, and all HED dispositions are documented.

Due to the potential to negatively impact plant and personnel safety, all HEDs that have been rated as Priority 1 or Priority 2 must be dispositioned through design change to correct the discrepancy and to address the HF concern.

Resolution of Priority 1 and 2 HEDs may not be deferred:

- All Priority 1 and 2 HEDs resulting from HFE Design Verification and Task Support Verification within the scope of ISV are corrected prior to ISV.
- All Priority 1 and 2 HEDs resulting from early, partial validation activities within the scope of ISV are corrected prior to ISV.
- All Priority 1 and 2 HEDs resulting from ISV are corrected prior to Design Implementation.
- During Design Implementation, all HEDs are dispositioned prior to declaring the system available for service.

Priority 3 HEDs may be dispositioned through design change, deferment, or as an HF-justified exception. This determination is made by the HF team. Deferment may be used to allow the impact of Priority 3 HEDs to be viewed in a more integrated context during validation testing or to be viewed in-situ, within the context of the as-built plant. Determination of a justified exception is made by the HF team based on overall acceptability within the context of the fully integrated design. Justification basis may also include additional literature review, trade-off studies, or design engineering evaluations as supporting information.

8.5 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 8.5.1 to 8.5.4, 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.

8.5.1 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.

8.5.2 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.

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]](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.

8.5.3 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

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]](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.

8.5.4 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.

Term	Definition
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.
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).

Term	Definition
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 19).
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.
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.

Term	Definition
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.
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.

Term	Definition
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.
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.

[[

]](a)(4)

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 9). 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 9): 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 9): 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.

[[

]](a)(4)

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. [[

]](a)(4).

Table A.3-1: Risk Level Assessment Matrix

[[				
				]](a)(4)

[[

]](a)(4)

A.3.2 Human Factors Engineering Application-Level Assessment

[[

]][(a)(4)]

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. [[

]][(a)(4)]

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

[[

]](a)(4)

[[

]](a)(4)

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

[[

]](a)(4)

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 9). The second was NUREG/CR-3331 (Reference 24).

Approximately ten years later, IAEA-TECDOC-668 (Reference 8) was issued, offering an international perspective on AOF and the earlier NRC works (Reference 9 and Reference 24). IAEA-TECDOC-668 recognized NUREG/CR-3331 (Reference 24) as the "most comprehensive approach to the problem of allocating functions in nuclear power plants," and recognized the preceding NUREG/CR-2623 (Reference 9) 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 10), which discusses NUREG/CR-3331 (Reference 24) 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 24) with input and modernization based on the practical considerations of IAEA-TECDOC-668 (Reference 8) and INL/EXT-13-30117 (Reference 10) 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.

- [[

  ]](a)(4)
- The AOF process includes input based on NUREG/CR-2623 (Reference 9) for allocation criteria that limit or preclude human participation, as well as criteria that define unique desirable human capabilities.
- [[

  ]](a)(4)

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:

- [[

]]^(a)(4)

- 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 [[

]]^(a)(4)

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

- [[

]]^(a)(4)

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.

[[

]][(a)(4)]

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.

[[

]][(a)(4)]

[[

]][(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.

[[

]](a)(4)

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.

[[

]](a)(4)

Figure B.2-3: Design Inputs and References

[[

]](a)(4)

[[

]](a)(4)

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

[[

]](a)(4)

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

[[		

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

[[		
		]](a)(4)

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 [[

]]^(a)(4)

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

[[		
		]]^(a)(4)

B.2.2.5.2 Task Support

[[

]]^(a)(4)

Table B.2-3: Task Support Definition

[[		
		]](a)(4)

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. [[

]](a)(4)

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

[[		

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

[[		

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

[[		

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

[[		
		]](a)(4)

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).

[[

]](a)(4)

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

[[		
		]](a)(4)

B.2.2.5.5 Operating Experience Associated with Task

[[

]](a)(4)

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. [[

]](a)(4)

- 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

[[

]][(a)(4)]

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 [[

]][(a)(4)]

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

]][(a)(4)]

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.

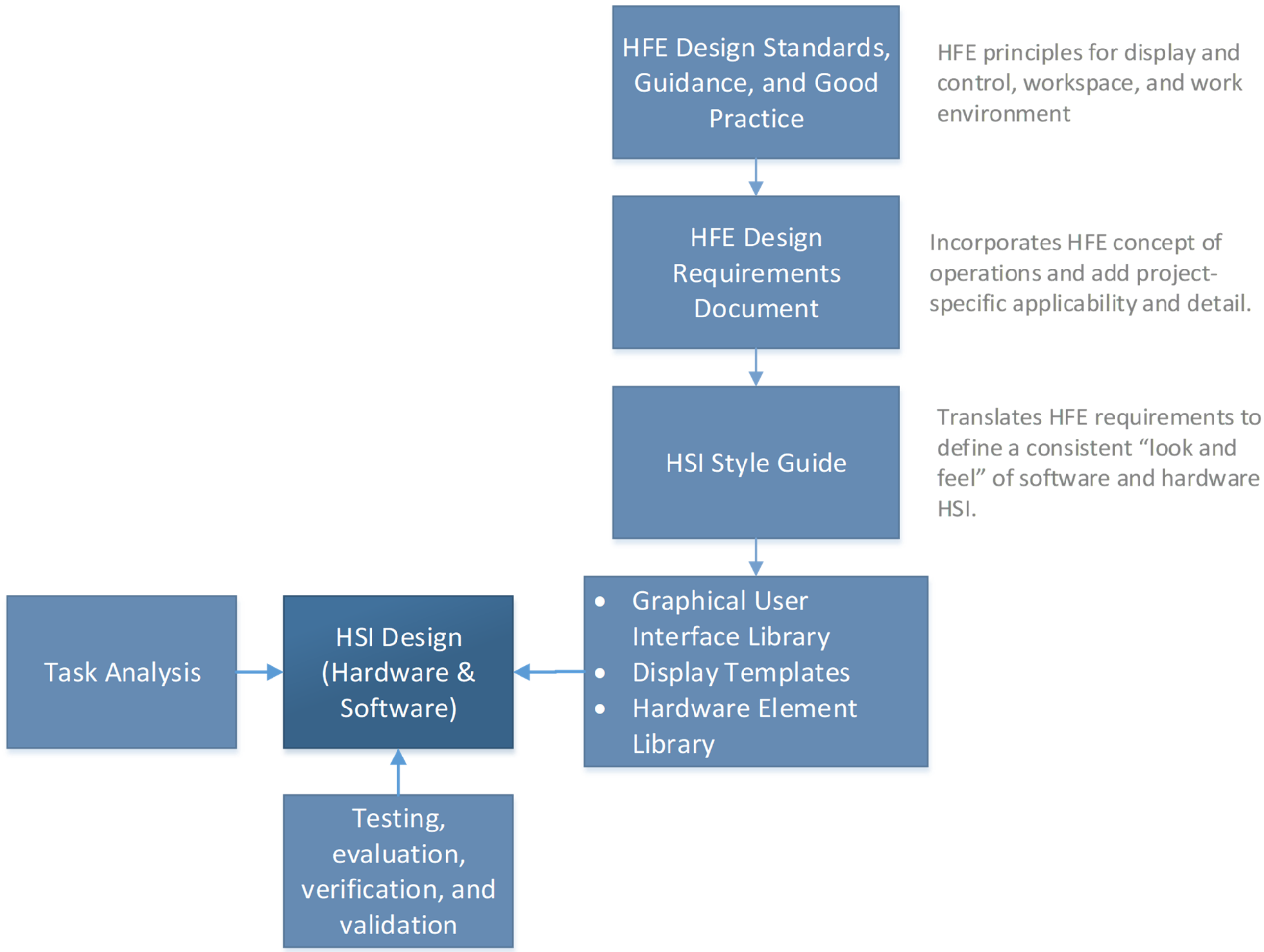

Figure B.3-1: Human-System Interface Design Process

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. [[

]][(a)(4)]

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

]][(a)(4)]

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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		]](a)(4)

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 -

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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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 3) and NUREG-0711 (Reference 4).

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.

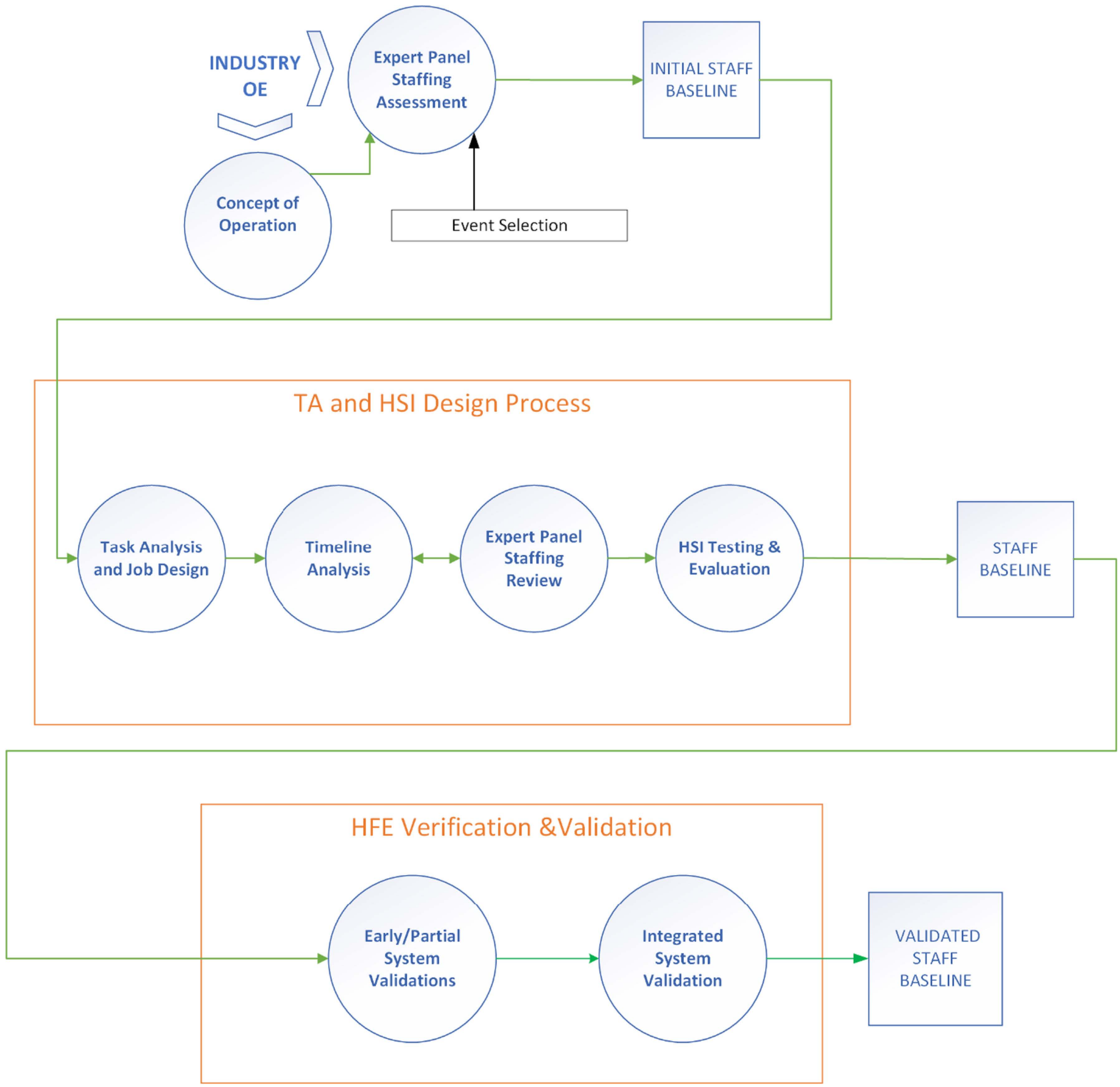

Figure C.3-1: Staffing Analysis Overall Process

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:

[[		
		]][(a)(4)]

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.

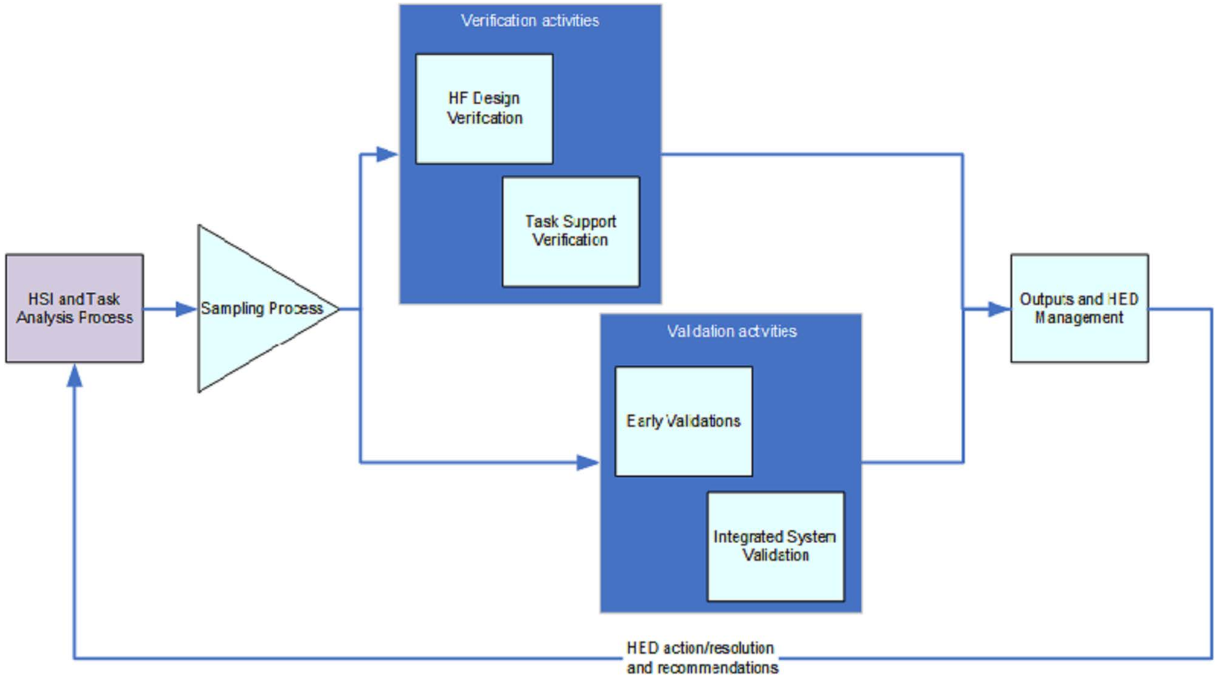

Figure D.1-1: Human Factors Engineering Verification and Validation Process Overview

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:

- MCR
- RSC
- 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 sampling process includes equipment and interfaces provided by contractor and sub-contractor suppliers as a part of the sampling population.

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.

[[

]](a)(4)

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. [[

]](a)(4)

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. [[

]][(a)(4)]

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.
- MCR, RSC, 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 19), 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 26), 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.

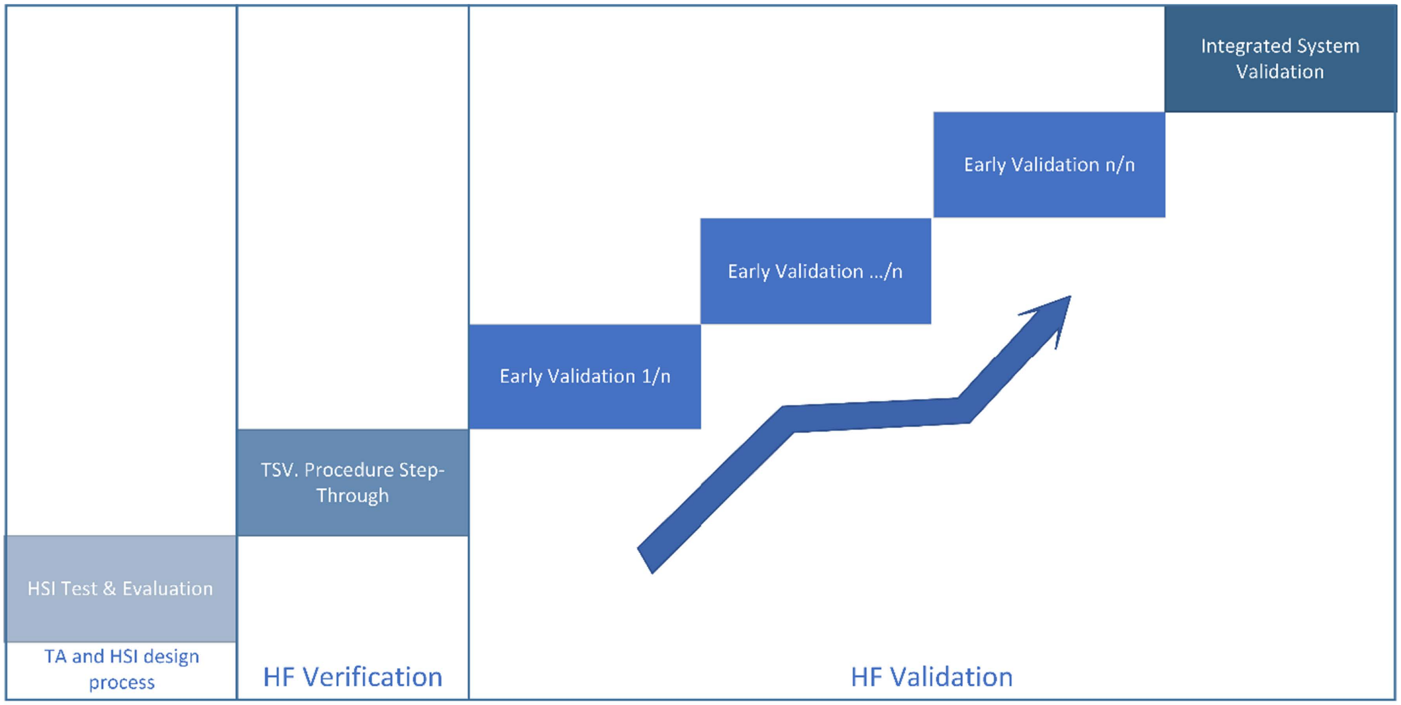

Figure D.6-1: Multiphase Testing and Validation Approach

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 19), 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 19), 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
- [[ ]](a)(4)

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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. [[

   ]](a)(4)

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 27) and NUREG/CR-6393 (Reference 20), 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 Situation Awareness Global Assessment Technique (SAGAT) is used, in which 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. To ensure sufficient test fidelity and generalizability of test results, the SAGAT is only used during early validation testing. This allows for more immediate data collection during early testing to identify areas where situation awareness deficiencies may exist, therefore allowing deficiencies associated with a Priority 1 or 2 HED to be addressed prior to ISV, and ensuring sufficient test fidelity and real-world generalizability of ISV results.

During early validation testing, ISV pilot testing, and ISV, questions to measure situation awareness are administered immediately following completion of a scenario, using the Situation Awareness Rating Technique (SART). During the SART, participants assess their own situation awareness using a predefined scale. This performance measure was selected due to having a predefined scale that is easy to administer and does not interrupt the simulation. However, due to the subjective, self-report nature of the SART, it may be influenced by the participant's confidence rather than actual situation awareness. Therefore, the SART is not used in isolation.

Assessment of situation awareness is supplemented through behavioral observations and performance measures including observer, video, and instructor station recordings of participant task performance (reaction times, number of errors, and task completion times) and participant debriefing and self-reflection of performance outcomes. These measures were selected because they can be done unobtrusively during ISV. However, they are also not relied on exclusively because they may not exclusively reflect SA, as other factors (e.g., skill, fatigue) can influence performance.

Additional supplemental information is also provided by a physiological measure, using participant eye-movement tracking, as gaze direction tends to strongly correlate with attention and cognitive activity. This measure was selected because it provides objective data and can be collected continuously without interrupting the simulation. However, because interpretation of data can be complex, it is not used in isolation.

As described above, the use of mixed performance measures during early validation testing helps to establish concurrent validity of the SART and the supplemental performance measures as a means of assessing situation awareness relative to the SAGAT. While no one measure in isolation may accurately reflect the participant's true level of situation awareness, assessment using mixed methods together enables the data analyst to more closely approximate the actual level of participant situation awareness and make an assessment regarding overall adequacy.

Situation Awareness Global Assessment Technique

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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.

Workload is not assessed only in isolation during ISV, but a part of a cumulative evaluation process that occurs across the design lifecycle:

- Workload is first assessed during AOF through review of initial function allocation using expert judgment to determine if the assigned functions per job role are suitable and sufficient.
- Workload is also assessed during task analysis, at the step level, with the selection of which task steps are performed in serial, and which task steps are performed in parallel; at the task level during workload analysis performed by a subject matter expert (see Table B.2-4 for details); and at the integrated task level (integrated workload analysis and timeline analysis) for operations that require interaction with multiple systems, across multiple plant states, and with a coordinated response that may involve multiple plant personnel.
- 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.
- During task support verification layout evaluation and procedure step-through, 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 in the HSI environment in terms of time and workload criteria.
- During the ISV, workload assessment is focused on independently confirming that previous efforts to address concerns have resulted in acceptable workload for the operators as described in the sections below.

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 28) and the NIOSH guideline, “Ergonomic Guidelines for Manual Material Handling” (Reference 29). 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 30), 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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Due to the subjective nature of self-report data, cognitive workload is also assessed during early validation testing, ISV pilot testing, and ISV in an integrated manner, in relation to the following measures:

- Cognitive workload is assessed in relation to situation awareness because the two measures have been found to have a significant inverse correlation with one another. Indications of poor situation awareness may indicate unacceptable workload (too high or too low).
- Behavioral Observations and Performance Measures: Assessment of cognitive workload is supplemented through observer, video, and instructor station recordings of participant task performance (reaction times, number of errors, and task completion times) and participant debriefing and self-reflection of performance outcomes. During a scenario or task, if operators could not perform procedures correctly and within

established time constraints, it may be determined that high/low cognitive workload contributed to the unacceptable performance.

- Physiological Measures: Additional supplemental information is also provided by using participant eye-movement tracking, as gaze direction tends to strongly correlate with attention and cognitive activity, and visual fixation patterns, blink rate, and saccades can provide insights into attention and cognitive load.

The rationale for the selected methodology of using an integrative approach as described above allows the HFE Analysts to triangulate cognitive workload using a combination of mixed methods, providing a more comprehensive assessment of cognitive workload.

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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