May 5, 2023

TP-LIC-LET-0072
Project Number 99902100

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

Subject: TerraPower Human Factors Engineering Concept of Operations White Paper

This letter provides the TerraPower, LLC White Paper, "Human Factors Engineering Concept of Operations." The full report contains proprietary information and as such, it is requested that Enclosure 3 be withheld from public disclosure in accordance with 10 CFR 2.390, "Public inspections, exemptions, requests for withholding."

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

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

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

Sincerely,

Ryan Sprengel
Director of Licensing
TerraPower, LLC

Enclosures:
1. TerraPower, LLC Affidavit and Request for Withholding from Public Disclosure (10 CFR 2.390(a)(4))
2. "Human Factors Engineering Concept of Operations" White Paper – Non-Proprietary (Public)
3. "Human Factors Engineering Concept of Operations" White Paper – Proprietary (Non-Public)

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

ENCLOSURE 1

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

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

I, George Wilson, hereby state:

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

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

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

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

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

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

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

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

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

   d. This information is not available in public sources.

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

I declare under penalty of perjury that the foregoing is true and correct.
Executed on: April 27, 2023

George Wilson

George Wilson
Vice President, Regulatory Affairs
TerraPower, LLC

ENCLOSURE 2

"Human Factors Engineering Concept of Operations" White Paper

Non-Proprietary (Public)

Controlled Document - Verify Current Revision

Document Title: Natrium Human Factors Engineering Concept of Operation				
Natrium Document No.: NAT-3038	**Rev. No.:** 0	**Page:** 1 of 28	**Effective Date:** 04/19/2023	**Natrium Safety Class:** N/A
Alternate Document No.: NEDO-33990	**Alt. Rev.:** 0	**Originating Organization:** GE-Hitachi (GEH)		**Quality Level:** QL-1
Export Controlled: No	**Attachments:** None			**Target Quality Level:** QL-1
Open Items: No	**Status:** Released		**Document Type:** RPRT	**Natrium MSL #:** HFE
Approval				
Approval signatures are captured and maintained electronically; See Electronic Approval Records in EDMS. ☐ Supplemental Signature Sheet Attached				

INFORMATION NOTICE

This is a non-proprietary version of NAT-3038 Revision 0, which has the proprietary information removed. Portions of the document that have been removed are indicated by an open and closed bracket as shown here: [[ ]][(a)(4)]. The superscript notation (a)(4) refers to the enclosed TerraPower affidavit, which provides the basis for the proprietary determination.

Important Notice Regarding Contents of this Report

Please Read Carefully

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

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

REVISION HISTORY

Revision No.	Effective Date	Affected Section(s)	Description of Change(s)
0	04/19/2023	All	Initial Issue.

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Acronyms

Acronym	Definition
3D	Three-Dimensional
AMS	Alarm Management System
AOF	Allocation of Function
ARP	Alarm Response Procedure
CBP	Computer-Based Procedure
COO	Concept of Operation
COTS	Commercial-off-the-Shelf
DRD	Design Requirements Document
EAL	Emergency Action Level
EI	Energy Island
EPRI	Electric Power Research Institute
ESF	Emergency Support Facility
FH	Fuel Handling
GEH	GE-Hitachi Nuclear Energy Americas, LLC
GVDS	Group-View Display System
HF	Human Factors
HFE	Human Factors Engineering
HFEPP	Human Factors Engineering Program Plan
HSI	Human-System Interface
I&C	Instrumentation and Control
IAEA	International Atomic Energy Agency
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
NCR	Nuclear Island Control Room
NI	Nuclear Island
OE	Operating Experience
PPE	Personal Protective Equipment
RO	Reactor Operator
RSF	Remote Shutdown Facility
SAMG	Severe Accident Management Guideline
SPDS	Safety Parameter Display System

Acronym	Definition
SRO	Senior Reactor Operator
SSG	Specific Safety Guide
SSR	Specific Safety Requirements
TA	Task Analysis
TLSA	Technology Licensing and Engineering Services Agreement between TerraPower and GEH dated May 24, 2021
TSC	Technical Support Center
TTC	Time to Consequences
U.S.	United States
V&V	Verification and Validation
VDU	Video Display Unit

1 INTRODUCTION

In support of the Natrium^{TM} design, a comprehensive Human Factors Engineering (HFE) program has been developed, as detailed in the Natrium HFE Program Plan (HFEPP) (Reference 1)[1]. The primary goal for ensuring adequate, integrated HFE in the design is to facilitate safe, efficient, and reliable operator performance during all lifecycle phases and all plant modes, including normal plant operation, abnormal events, refueling and maintenance outages, and accident conditions.

1.1 Purpose

The HFE Concept of Operation (COO), sometimes referred to as a concept of use document, describes the ways users interact with the Human-System Interfaces (HSIs) and with one another to monitor, control, and maintain the plant so that it functions in a safe, secure, regulatory compliant, and efficient manner. The HFE COO acts as a baseline set of assumptions regarding the operational plant. This includes job design aspects such as the definition of user roles, assumed minimum staffing, user population characteristics, aspects of work coordination relevant to the design, and crew communications.

The HFE COO includes the following:

- Descriptions of the use of technology
- Principles for Allocation of Functions (AOFs) or automation level
- Key design features of relevance to user task performance

In addition, the HFE COO sets out the relevant results of Operating Experience (OE) reviews that affect the design to support user task performance and to ensure that lessons learned from existing plants are adequately propagated into the new plant design.

The HFE COO is prepared early in the design because it is the basis of and input to all further HFE activity defined in the HFEPP (Reference 1). It is used by the Human Factors (HF) engineers doing analysis and providing design support to ensure all HF engineers have a common agreed upon set of user and operational assumptions. It is also used by design teams to understand and consider user capabilities and limitations when making design decisions and equipment selections that affect usability.

1.2 Scope

This HFE COO is based on a single unit site. The HFE COO applies to the Nuclear Island (NI)-related HSIs included within the following locations:

- Nuclear Island Control Room (NCR)
- Remote Shutdown Facility (RSF)
- Fuel Handling (FH) control room
- Local controls
- Emergency Support Facilities (ESFs)

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

2 REQUIREMENTS AND TECHNICAL BASIS

2.1 Requirements

Requirements management and the use of requirements management tools is in accordance with the HFEPP (Reference 1).

2.2 Technical Basis

In addition to the requirements discussed in Section 2.1, the HFE COO also considers the relevant good practice provided in the following documents:

- International Atomic Energy Agency (IAEA) Specific Safety Guide (SSG-39) (Reference 2)
- IAEA Specific Safety Requirements (SSR)-2/1 (Reference 3)
- International Electrotechnical Commission (IEC) 60964:2018 (Reference 4)
- IEC 60965:2016 (Reference 5)
- IEC 61839:2000 (Reference 6)
- NUREG-0800, Section 7.4 (Reference 7)
- NUREG-0711 (Reference 8)

These codes and standards are inputs to the overall development of the HFE COO.

Technical basis inputs for the following specific sub-topics are included in the relevant subsections of this document:

- Procedures
- Alarms
- User group description
- HSI guiding design principles and considerations
- Monitoring and control area layout and usage assumptions

2.3 Operating Experience

Additional technical basis is provided by input from the OE collected during the HFE OE review process.

3 OPERATIONAL PHILOSOPHIES AND CONCEPTS

3.1 Operations

The overall HFE design, including roles, responsibilities, and task assignments, supports the authority, responsibility, and oversight of the reactor by operations personnel.

The overall operational philosophy for the HFE COO is:

- To leverage the functionality and OE from existing designs and to use modern standards and technology to remove the burden and risks associated with manual operation.

- To leverage HF in design, including identification of roles, responsibilities, and task assignments, to ensure the plant supports the authority, responsibility, and oversight of the plant by plant personnel.
- NI operations (process controls) are largely separate from Energy Island (EI) operations. EI related information is provided to NI operations based on significance and effect on NI operation.

3.2 Automation

The established level of automation is based on AOF analysis. Tasks are assigned to the human, machine, or a shared combination of both human and machine.

Each allocation is based on criteria for assignment that considers human and machine capabilities and limitations. Some allocations are initially dictated by regulations, standards, or customer requirements. These allocations are also evaluated against HF allocation criteria to ensure that the selections are appropriate assignments for human or machine.

When evaluation of a function or task allocation does not clearly indicate that allocation to machine or human is required, and plant availability could be affected by the allocation decision, preference is given to machine allocation, with due consideration to feasibility. When automation is used, the overall design supports crew situational awareness of the automation status and the capability of the crew to take control or place the plant in a safe condition, if necessary. Also, when automated process control actions are provided, these actions are visibly cross-referenced to procedure steps. This association supports transition to manual operation to correct automation malfunction if such operation is permitted by requirements and allocation criteria.

To ensure an acceptable level of workload and situational awareness, the overall plant-level mix of automation and human tasks are evaluated as part of the design, evaluation, and testing process following Task Analysis (TA).

The following are considered during the HFE AOF for automation features based on OE:

- Electrical breaker operation that requires synchronization or protection against out-of-phase connection by interlocks
- Control rod movement to eliminate unacceptable consequences
- Long-term monitoring tasks (e.g., longer than 20 minutes)
- Tasks when temperature and radiation levels are a concern
- Any time-critical actions
- Control rod drive mechanism driveline disconnect
- Usage of automatic optimization software for determination of refuel sequence
- Frozen sodium system recovery
- Reactor power calorimetric
- Creating technical specification surveillance packages
- Providing surveillance status for mode change checklist
- [[ ]](a)(4)

- Sodium system cold and cesium trap temperature control
- Refueling component and equipment processes

These tasks are considered for shared automation and manual features based on OE:

- In-core refueling task automation with human oversight, with the capability to perform required actions manually using the machine with actual tactile feedback to the operator
- Tasks involving variable inputs, processes, and environments, such as avoiding changing obstacle locations when positioning cask handling machines to storage locations

The following is a consideration for HSI features supporting automation based on OE:

- Design controls which require multiple deliberate actions to disable automatic safety features

3.3 Communications

A reliable, fixed communication system is included in the plant design to provide secure point-to-point communications among the NCR, FH control room, and NI local controls. The fixed communication system provides for paging or announcements over speakers in the areas of the plant accessed by workers. The fixed communication system is supplemented by wireless communication that is supported plant-wide with repeaters and does not cause interference with the plant Instrumentation and Control (I&C) systems. TA identifies worker communication needs and methods to support the design of specific communication systems.

Reliable, secure communication channels are provided between NI and EI personnel and locations. Communications between the EI and NI consist of voice communication, supplemented by written communication, and communication of information about plant status (automated controls, process measurements, equipment status, alarms, and trip indications) to support the roles and the tasks performed in these areas.

To preserve NI operator situational awareness and vigilance while maintaining reactor operations without distraction, EI communications are focused on EI operations that have a significant effect on NI operation (e.g., cold salt tank level, rate-of-change of cold salt tank level, and cold salt tank pump operating status). Content and level of communications are developed as part of the communication strategy between EI and NI.

Reliable, secure communication channels are also provided between the following:

- NCR and ESFs
- NCR and FH control room
- RSF and ESFs

Selection and design of communications system equipment is developed in accordance with HF design requirements in the HFE Design Requirements Document (DRD). Detailed design of the NI communications system is provided though an NI communications system design description.

3.4 Use of Closed Circuit Television

Closed Circuit Television feeds are provided throughout the plant to give users the capability to monitor areas that are otherwise inaccessible or have a compromised view due to angles or obstructions. These feeds are also used to reduce the burden of operator patrols or rounds.

Video feeds are provided to the respective NCR locations in a manner that supports effective user monitoring performance without affecting the functionality or performance of the information and control systems. The cameras have the capability to pan, tilt, and zoom to provide full monitoring of each location.

3.5 Procedures

Procedures are produced and validated using current nuclear best practice procedure development methods. Procedure development integrates OE findings related to poor procedure design or opportunities for procedure improvement.

Operating procedures include the provision of instructions in the NCR, RSF, and FH control room for operation of plant systems and control devices, information and recording systems, communication equipment, and any other equipment operated from these locations. Operating procedures for manual actions taken from the NCR, RSF, and FH control room are simple and clear, and contain the requisite level of detail to support performance of manual actions. Procedures for the NCR, RSF, and FH control room are based on the same principles, deviating only where differences are imposed by the respective control facilities and the tasks performed therein.

[[

]](a)(4) CBPs include a place-keeping feature and may include other additional features (such as embedded live plant data) to provide enhanced task support, as determined during TAs and CBP software evaluations. A different CBP type [[ ]](a)(4) may be selected for each type of procedure as long as a simple and clear engineering approach, consistent visual coding, usability, and user interaction scheme is maintained.

The HSIs in the NCR are designed to support use of CBPs [[ ]](a)(4). Selection of a CBP system and design of the CBP displays are developed in accordance with the HFE DRD and using guidance that includes the following standards:

- IEC 62646:2016 (Reference 9)
- IEEE Standard 1786 (Reference 10)
- Electric Power Research Institute (EPRI) 3002004310 (Reference 11)

Storage space is provided in the NCR, RSF, and FH control room for a hardcopy set of operating procedures to support required operation and any operator aides (such as checklists or memory aids). In the NCR, storage and laydown space is provided for drawings up to architectural paper size ARCH E.

3.6 Alarms

Alarm philosophy and principles are defined in Sections 3.6.1 through 3.6.4. The alarm HSI standards for color coding of alarm priority, status (acknowledged, reset), silence and acknowledgement protocols, and use of plant level, system, and individual alarms are designed using conventions defined in the HFE DRD as appropriate to the user group defined in Section 5.

The HSI alarm philosophy design process addresses the following topics:

- Roles and responsibilities for alarm management
- Alarm documentation

- Alarm design guidance
- Alarm HSI design principles

The alarm management specification addresses the following topics:

- Implementation guidance, including training, commissioning, and testing
- Alarm system maintenance requirements
- Alarm system performance monitoring objectives and guidance
- Alarm system aspects supporting change management
- Alarm system aspects supporting system audits

3.6.1 Purpose

The plant alarm systems are used to direct the user's attention and generate a response to rectify an equipment malfunction, process deviation, or abnormal condition that could affect safety. User attention is gained using unique audible and visible indicators.

3.6.2 Alarm Design Principles

As stated in the HFEPP (Reference 1), an Alarm Management System (AMS) is developed, designed, installed, and managed using HF good practice as defined in IEC 62241:2004 (Reference 12).

A condition is defined as an alarm if it falls outside of the normal and expected range and it requires a timely operator response (known as a darkboard concept and applicable when at full-power operation). Other information or conditions that do not require a timely operator response are provided to the operator in an alternate, non-alarm, form. Alarms are not in their alarm state when there are no actions required (e.g., there is no alarm when equipment is out of service).

Alarms are for specific alarm conditions rather than a general trouble alarm that necessitates a user having to search for what conditions caused the alarm. Exceptions to this principle are evaluated on a case-by-case basis for:

- Vendor-packaged or Commercial-off-the-Shelf (COTS) equipment
- Systems or equipment with many failure/fault modes which have a local panel showing details of alarm cause and where there is adequate time to send an operator into the field to determine the specific grouped alarm cause.

The design goal for the AMS is to avoid alarm avalanche and support acceptable operator workload by limiting alarms received during a design basis event or design extension event to those with high operational value.

In addition to alarm design principles, the following are considered during alarm system design based on lessons learned, OE, and HF good practice:

- The alarm system includes an alarm log feature that is sortable by time. This functionality supplements the first-out functionality.
- The alarm design documentation includes a summary of the conditions that generated the alarm and a summary of required alarm response actions. This information forms the basis of the Alarm Response Procedure (ARP).
- Each alarm is identified on logic diagrams.

- Each alarm requires a corresponding ARP. The HSI design includes a method to access the ARPs via the HSI or CBP interface.
- Changes in the status of systems that necessitate an alarm include deviations from normal operational limits, loss of availability of safety systems, or unplanned unavailability of standby equipment.

3.6.3 Alarm Prioritization

The AMS uses a four-level priority scheme with Priority 1 being the highest and Priority 4 being the lowest. Priority is selected based on the combination of a hazard index and a Time to Consequences (TTC) index as provided in Table 3-1. Alarm priority is coded by at least two distinct means (e.g., location, labeling, shape), with color used as the secondary code.

Table 3-1: Alarm Priority Matrix

[[	
	]](a)(4)

3.6.4 Alarm Rationalization

Alarm rationalization is governed by the HSI design process. Alarm rationalization is performed on the full inventory of alarms established through the TA and the system design process. The alarm rationalization process includes the following basic steps:

1. Confirm that the candidate alarm meets the definition of an alarm
2. Assign or confirm the alarm priority

3. Group like alarm signals (multiple channels representing the same parameter)
4. Specify alarm filtering when appropriate (alarm expected for the condition such as plant mode)
5. Specify alarm suppression when appropriate (condition encompassed by another alarm)

4 TASK ANALYSIS CONSIDERATIONS

4.1 General Task Analysis Considerations

The following are general TA considerations based on OE that are used as input during the TA process:

- User support for monitoring the status of important equipment through a consolidated interface (safety system status and technical specification monitoring functions)
- Lineup sequences from low to high pressure when the flow path includes a static pressure-reducing element (e.g., pressure breakdown orifice)
- Minimizing equipment operation in an unloaded state
- Actions and sequences that, if performed incorrectly, result in unacceptable consequences (specify independent or concurrent verification as appropriate)
- When second part verification is required prior to continuing with a task sequence
- Alarm for doors with positions required to protect safety equipment and consideration of a pass-through time delay to prevent nuisance alarms
- Guidance or interlocks to prevent high current situations that could occur by momentarily stopping and restarting a motor
- Lineup sequences of supply and exhaust fans such that negative pressure is maintained if applicable
- For equipment protection, consideration of lineup sequences for heat exchangers that result in establishing flow of the cooler fluid prior to initiating flow of the hotter fluid
- Functional testing of specified safety functions to verify proper system operation following maintenance
- Indications and alarms provided when loss of ventilation results in inoperable fire detectors
- Provision of operator aids to support understanding plant conditions regarding operating limits and conditions, such as power versus flow
- Inclusion of conspicuous and clear criteria and thresholds for reactor scram and shutdown
- Calibration tasks identifying conditions of inoperability of important instrumentation during adjustment
- Providing appropriate task support for placing instruments back in service to prevent perturbations on instruments that share a common sensing line
- Parameter hold values considering tolerance bands from the arming of logic circuitry, if applicable

- Tasks for transferring loads to an alternate power source which include guidance on verifying bus voltages prior to transfer
- Analyses including tasks performed by the supervisor, including displays to be accessed, communication needs, and a space for collaboration
- Potential for contamination when conducting manual refuel operations or maintenance on primary sodium systems
- The physical challenge of sodium maintenance tasks that require a glove bag
- Inclusion of abnormal events in detailed TA because they may be consequential and complex
- Reliance on indirect means, which represents a potential for error, due to the opacity of sodium which limits visibility for in-vessel maintenance or refueling tasks
- Hazards associated with working with sodium due to its reactive nature
- Inclusion of allowances for sodium 24 decay for sodium system tasks to limit exposure
- Failed fuel contamination and cesium exposure concerns
- Graphical presentation of applicable operating boundaries to ease detection of a parameter outside limits
- Specification of shape-coded switches if there is considerable potential for operator confusion or error
- Consideration of the impediments related to natural disasters or internal plant events when analyzing associated tasks

4.2 Specific Task Analysis Considerations

The following are specific TA considerations based on OE:

- System design, workplace design, and task performance support minimizes the likelihood of human error and mitigates the unacceptable consequence of incorrect control rod selection and positioning.
- Station blackout results in time pressure and multitasking and includes physically challenging tasks, and therefore is included in detailed task and workload analysis.
- Changeout of a primary sodium pump is a complex task with plant life implications and therefore is included in detailed TA.
- Rapid drain of an intermediate sodium loop is a challenging task that has historically had time limitations and influences the minimum staffing count.
- A sodium fast reactor responds rapidly to reactivity changes as compared to water cooled reactor designs.
- Crane operations are sources of human errors and therefore are included in detailed task and workload analysis.
- Any manual heat trace operations are included in detailed task and workload analysis based on performance of legacy designs.
- Manual cask operations are included in detailed TA due to being physically challenging.

5 USER GROUP DESCRIPTION

5.1 Staffing, Roles, and Responsibilities

The staffing, roles, and responsibilities in this section are assumptions made for the HFE conceptual design and are based on collective OE.

These initial assumptions are updated based on inputs from the plant maintenance and operations strategy and are evaluated for acceptability during staffing analysis. The final staffing, roles, and responsibilities are validated for final acceptability during HFE Verification and Validation (V&V) testing. Training for these roles is delivered based on the training program plan. Additional detail regarding these processes is provided in the HFEPP (Reference 1).

The roles and titles described in Section 5.1.1 are provided to allow HFE TA and other HFE design support activities to proceed based on assumed personnel competency and assignment to specific tasks. This provides the baseline staffing assumptions for workload analysis and input to the training and qualification program development.

The role, titles, and number of personnel required to be on-site and fulfilling each role in any given plant mode, including refueling and maintenance outages, is undefined and is not dictated by the job functions listed in this section. Except for the reactor operations minimum staffing complement, the role descriptions may be separate individuals or may be performed by individuals in other roles in some cases, depending on required skills and workload, as well as the final plant design.

There is not a separate shift technical advisor role included in staffing. This is based on the following considerations:

- The operator training program includes topics applicable to a typical shift technical advisor training and qualification program. As stated in Section 5.1.1.1, the shift manager has the training and qualifications to provide engineering expertise to the shift.
- The inherent safety features of the design result in lower operational complexity and improvements in plant safety including reduced reliance on operator actions.

5.1.1 Role and Responsibility Descriptions

5.1.1.1 Shift Manager

At all times and in all plant modes, a shift manager is present on-site. The shift manager is a Senior Reactor Operator (SRO) that is responsible for overall plant operations on the assigned shift. The shift manager maintains the broadest perspective of operational conditions affecting the safety of the plant. The shift manager functions as senior management whenever higher line managers are absent from the site, and in this capacity initiates and directs any site emergency response actions. The shift manager has the training and qualifications to provide engineering expertise to the shift for assessment of transients and other abnormal conditions.

The shift manager has the responsibility for determining Emergency Action Level (EAL) classifications. The shift manager makes the EAL classification in 15 minutes and has an additional 15 minutes to report out, as required by 10 CFR 50 Appendix E (Reference 13).

5.1.1.2 Control Room Supervisor

In any operational mode other than safe shutdown or refueling, the control room supervisor (who is qualified as an SRO) is in the NCR at all times to supervise reactor operations. The control room supervisor:

- Ensures plant operations are conducted in accordance with appropriate standing orders, the off-site dose calculation manual, unit operating procedures, and technical specifications
- Implements emergency response guidelines and directs procedure steps to stabilize the plant following an emergency or abnormal condition
- Authorizes changes in equipment and system operational status
- Investigates the cause, assesses adverse effects on plant operation, and reports abnormalities to the shift manager during abnormal or unusual events
- Authorizes and verifies plant conditions are suitable for maintenance and testing activities
- Ensures equipment clearances and tagging functions are performed

This position may be temporarily filled by the shift manager when necessary.

After the initial verification steps, the control room supervisor provides a backup to the shift manager's decision for EAL classification.

5.1.1.3 Reactor Operator

Each shift contains two Reactor Operators (ROs) that are equally qualified to monitor and control the reactor. The role of the RO is to maintain broad awareness of activities in the NCR and plant and to coordinate with the EI operator during start-up, shutdown, normal plant operation, and off-normal events.

One RO is responsible for the NI and is located in the at-the-controls area as defined by Regulatory Guide 1.114 (Reference 14).

The second RO (not at-the-controls) is not required to always remain in the NCR and is assigned any required field monitoring or tasks that are necessary. The second RO is also available to relieve the RO at-the-controls when needed.

5.1.2 Minimum Operations Staffing

Minimum operations staffing is based on the number of operators needed to perform all simultaneous operations necessary to bring the plant into a safe state. HFE considers minimum operations staffing as it develops a design that can be safely operated by this minimum number of personnel in the specified condition. HFE also establishes testing scenarios that confirm the adequacy of the staffing and the design. The minimum staffing per shift for initial HFE design input is provided in Table 5-1 and is compliant with 10 CFR 50.54(m) (Reference 15).

Table 5-1: Minimum Nuclear Island Control Room Operations Staffing

# of Nuclear Power Units Operating	Position	One Unit; One Control Room
None	SRO	1
	Reactor Operator	1
One	SRO	2
	Reactor Operator	2

This NCR staffing is divided into the roles and responsibilities shown in Table 5-2.

Table 5-2: Assumed Nuclear Island Control Room Operations Staffing Roles

Role	Number	Primary Location
Shift Manager	1	Shift manager office adjoining the NCR
Control Room Supervisor	1	Control room supervisor workstation within the NCR
NI Operator	1	NI operator workstation within the at-the-controls area in the NCR
NI Relief Operator	1	EI operator workstation within the NCR OR On-site/within proximity of the NCR (protected area)

5.2 Physical Characteristics and Capabilities

The design is targeted primarily for a United States (U.S.)-based user population with expanded considerations for additional deployments. The following user population characteristics and assumptions do not include measurement modifications or perceptual limitations caused by the wearing of Personal Protective Equipment (PPE).

5.2.1 Anthropometric Data

This section contains the anthropometric measurements for the 95th percentile male and 5th percentile female for the target user population. This information is used in conjunction with the design requirements provided in the HFE DRD for accommodating these upper and lower bounds. The composite Three-Dimensional (3D) design and engineering process uses appropriately sized 3D computer-assisted drawing mannequins based on this anthropometric data to facilitate the design of workspaces to meet the HFE DRD ergonomic requirements.

Where a task requires the use of PPE, accommodations in the workspace and HSI design include adjustments to the anthropometric data to accommodate PPE using guidance provided in MIL-STD-1472H (Reference 16).

Anthropometric measurements are based on NUREG-0700 (Reference 17) and on Part 3 of International Organization for Standardization (ISO) 7250-3:2015 (Reference 18). To ensure that the design has sufficient flexibility, the user population data is defined using a broader range of data than either standard contains individually. For the 5th percentile female population, the lower value from the standards was selected. For the 95th percentile male population, the higher value from the standards was selected. The resulting measurements are used to represent the user population as an input to the design.

5.2.2 Strength Data

The design considers the maximum strength capability of the 5th percentile users to ensure that tasks involving moving or removing components, actuators, operators, or other items can be accomplished by this set of users who represent the lower bound of the strength data. The maximum strength capability for the 95th percentile users is also considered in design to prevent user damage to design elements through use of unexpected force. The strength capability data is derived using the methods and data in Part 1 of ISO 11228-1:2021 (Reference 19) and Part 2 of ISO 11228-2:2007 (Reference 20). Base strength data derived from the standards provides maximum capability. Design considers the effect of distance, frequency, duration, and posture associated with a task in conjunction with these values.

5.2.3 Handedness

The user population includes both right and left-handed individuals.

5.2.4 Visual Characteristics

The user population is compliant with site vision requirements to ensure employees have the appropriate level of visual acuity and contrast sensitivity necessary for the job.

Operating organizations are not permitted to discriminate against persons with color perception deficiencies when hiring.

Therefore, the design is based on a user group with corrected vision of 20/20 and some portion of that group having color perception deficiencies. This is accounted for in the selection of color combinations in HFE design and in the use of redundant coding (color being secondary) to convey information on digital displays and in indicator light pairs.

5.2.5 Accommodation for Physical and Cognitive Diversity

Operating organizations are not permitted to discriminate against persons with physical or cognitive limitations when hiring. However, due to the physical and hazardous nature of the work in the plant, including during outages and in worst-case accident scenarios, physical and cognitive capability are such that the most onerous task for a job role must be able to be performed to required standards.

Based on the role definitions in Section 5.1 and the known characteristics of representative tasks in existing nuclear power plants, the user population performing all roles defined in this document, except for work management and outage management, do not use mobility aids such as wheelchairs, walkers, canes, or crutches, and all personnel fulfilling the roles defined in this document are fully cognitively capable.

Areas of the plant that are occupied or frequently used by personnel other than those in the job roles defined in this document are designed to accommodate physically and cognitively challenged persons. This type of data is considered by designers to ensure the plant meets local regulatory requirements for emergency access and egress.

Anthropometric data and other inclusive design requirements for persons using mobility aids or with sensory or cognitive impairments are available in various standards. The architectural and plant building design teams have design and process requirements for confirming the design meets global accessibility standards for buildings.

5.3 Population Standards and Coding Stereotypes

U.S. customary units are used as the displayed HSI unit of measure. While most population stereotypes are similar among user populations, differences are accommodated during design coding. Based on a review of population standards and coding stereotypes, to avoid coding conflicts and to reduce the potential for user errors across user populations, the design excludes [[
]](a)(4).

6 HUMAN-SYSTEM INTERFACE GUIDING DESIGN PRINCIPLES AND CONSIDERATIONS

6.1 General

The NCR, FH control room, and RSF are designed to support NI tasks that include the following (based on IAEA SSR-2/1 (Reference 3) and IAEA SSG-39 (Reference 2)):

- Assessing the overall status and performance of the plant in any condition and providing necessary information to support operator actions
- Monitoring the status and trends of key plant parameters (such as reactor power and rates of power change)
- Operating the plant safely during all operational states, automatically or manually
- Taking measures to maintain the plant in a safe state or return it to a safe state
- Maintaining the plant within the specified limits and conditions on parameters associated with plant systems and equipment
- Monitoring for failure of critical instrumentation and equipment
- Confirming that safety actions for the actuation of safety systems are automatically initiated when needed and that the relevant systems perform as intended
- Implementing emergency operating procedures and Severe Accident Management Guidelines (SAMGs)

The HSIs used for monitoring and control of the NI follow design-based OE and HF good practice:

- HSIs use consistent, standardized design conventions.
- HSI layout and arrangement considers the I&C architecture restrictions and meets operability/viewability requirements.
- Operator responsibilities, assignments, and crew task-sharing practices are considered in the layout, arrangement, and configuration of HSIs.
- When VDUs are used, the number and size of display screens provided support user’s tasks without the need to toggle back and forth among displays.
- HSIs on displays and panels for the NCR, RSF, and local controls are ergonomically designed and use a common interface protocol, display format, and coding as specified in the HFE DRD.
- Coding for the design provides differentiation among units, systems, channels, and equipment.
- The design includes provisions for on-line monitoring and wireless equipment monitoring to allow operator rounds to be reduced, along with the associated radiation exposure.

- The design provides the ability for operators to establish user-defined value monitoring that includes an audible alert when value thresholds are exceeded.
- Considering the control technology, the design supports the ability to query control input status (such as interlocks, start permissives, and auto start signals) at the point of operation.
- The Safety Parameter Display System (SPDS) is integrated within the overall NI HSI design.
- Workstation hardware, VDUs and all other interface components are acquired and integrated with as many COTS products as possible, with HFE review and oversight to ensure the COTS products meet HF design requirements, or that any non-compliances are acceptable (and justification for the non-compliance is recorded).

6.1.1 Accident Monitoring

Information displays for monitoring accident conditions in the plant are provided and displayed in the NCR in accordance with the roles and responsibilities of operating personnel. Where accident monitoring information displays are near other types of displays, differentiation and emphasis is placed on the identification of accident monitoring information.

Accident monitoring displays indicate the values of variables needed by plant operators in accident conditions to enable them to:

- Take preplanned manual actions (this refers to anticipatory actions and damage mitigation and management actions, not to directly credited operator actions such as time-critical operator actions) to bring the plant to a safe state
- Determine whether the fundamental safety functions are being fulfilled
- Determine the potential for a breach, or the presence of an actual breach, of the barriers preventing release of fission products
- Determine the status and performance of plant systems necessary to mitigate consequences of design basis accidents and bring the plant to a safe state
- Determine the actions needed to protect the public from a release of radioactive material based on existing conditions (e.g., radiological conditions in the plant and its surroundings and the meteorological conditions)
- Implement SAMGs as applicable

The accident monitoring variables are selected in accordance with Regulatory Guide 1.97 (Reference 21) and IEEE 497-2016 (Reference 22).

Safety-related functions credited in the safety analyses to satisfy design basis accident acceptance criteria are automatically initiated or passively performed, relying on no operator actions for successful performance. Because of the inherently safe and passive nature of the plant design, the scope of SAMGs and emergency planning functions is more limited in the plant and have a shifted focus on confirmatory and anticipatory actions to limit the effect rather than to mitigate large scale releases and damage that might be typical in a traditional light water reactor design.

6.1.2 Safety Parameter Display System

The integrated SPDS function includes the variables selected for accident monitoring as described in Section 6.1.1. The SPDS function ensures that operator displays contain sufficient information for monitoring fundamental safety functions to support the diagnosis and mitigation of design basis events.

Functionality to support integrated SPDS includes:

- Display of variables in the full range expected during normal operation and abnormal or emergency conditions
- Provisions for data trending
- An indication when limits are approached or exceeded using simple diagrams with well-presented safety margin
- Display of safety system status

The SPDS includes displays that assist the plant staff in executing emergency procedures, severe accident procedures, and site emergency response to limit the effect of accident conditions.

6.2 Mitigation of Inadvertent Actuation or Disablement

To minimize the risk of inadvertent actuation or disablement, the following design principles are used to guide HSI development:

- Selection of hardware-based HSI control types preventing inadvertent actuation
- Placement of hardware-based HSI controls with sufficient spacing among controls
- Placement of hardware-based HSI controls on panel and console locations that cannot be accidentally bumped, pressed, or snagged
- Use of engineering controls for hardware-based HSI controls (such as flip covers, plastic removable covers, and doors) and confirmatory actions for software-based HSI controls
- Design controls so that disabling automatic safety features requires multiple deliberate actions
- Password protection or warning flags on screens with keypads on which a number or value can be entered that causes an equipment or plant trip
- Design control features to prevent inadvertent draining of reactor coolant
- Control entries for any particular action that offer the operator only the options and controls available for selection

6.3 Design for Operations, Maintenance, Inspections, and Testing

The NCR, RSF, and NI-related local plant areas are designed with sufficient access, clearances, and HSIs to support operations, maintenance, and testing activities.

To achieve this, the following design principles are followed:

- HSIs are designed so that routine maintenance activities, including in-service inspections, and periodic testing are performed during at-power plant operation to the greatest extent practical.
- HSI layout includes sufficient working and laydown space for component repair or replacement, and for cleanup activities.
- The design allows for remote monitoring and observation of systems and components.

6.4 Work Environment Design Principles

The design of the NCR and RSF includes appropriate lighting levels (including under degraded conditions), thermal environment, and noise levels to support habitability and human task performance, in accordance with HF design requirements and task requirements.

The design ensures that the NCR and RSF are equipped with adequate facilities to support staffing and required mission time.

7 MONITORING AND CONTROL AREA LAYOUT AND USAGE ASSUMPTIONS

Development of the environment, work areas, and HSI used to control the NI utilizes HFE design concepts and drawings, using input from HFE requirements, OE, HF expertise, and feedback from stakeholders.

The conceptual designs define the basic form, content, equipment, layout, and environment used by plant personnel to monitor and control the plant. More detailed design iterations integrate task support requirements from the TAs and design requirements from the HFE DRD. These layouts and drawings are finalized in NI control building drawings through formal reviews by multiple disciplines and reviews against workplace design guidelines. Additional details regarding this process are found in the HFEPP (Reference 1).

Sections 7.1 through 7.6 define the HF design assumptions, expected usage, and staffing for different NI work areas that provide input, along with HF requirements, OE, HF expertise, and feedback from stakeholders into the development of the monitoring and control area designs and drawings.

7.1 Plant Layout

The following considerations for plant layout are designed to facilitate the traffic flows, task needs, and communication needs of the plant staff:

- Access points to the NCR are in a location that does not distract the operating crew (e.g., back or side location out of the line-of-sight of plant overview monitoring).
- The NCR includes a sliding window to a hallway or work control area so that discussions can occur without the need to enter the NCR proper.
- A work control center office is provided in a location outside the NCR to avoid distracting the operating crew.
- The shift manager office is located within the NCR habitability boundary, with line-of-sight into the NCR. To avoid distraction to the operating crew, means of accessing the shift manager office is not only through the NCR.
- An area in the NCR or in an adjacent office is provided to allow for emergency communications with minimum disturbance of the operating crew.
- Restroom and break facilities are located within the NCR habitability boundary.

7.2 Nuclear Island Control Room

7.2.1 Nuclear Island Control Room Usage

The NCR is the primary location for plant NI monitoring and control during normal, abnormal, and emergency conditions, and includes the functionality described in Section 6.1, in alignment with the principal design criteria for control rooms.

7.2.2 Staffing and User Task Support Needs

The NCR is optimally designed for nominal staffing (the control room supervisor and two ROs).

The following roles have a seated workstation designed with enough VDUs to support the specific control, monitoring, procedure use, communication, and work coordination needs for that role:

- Control room supervisor
- NI operator
- NI relief operator

Each NCR workstation also contains space for a role trainee. Adequate laydown areas are provided for documents (such as procedures), and sufficient hardware and workspace is provided to perform communications tasks.

The control room supervisor workstation contains space for the shift manager.

The NCR contains a predominantly VDU-based Group-View Display System (GVDS) in a central location that displays a consolidated overview of plant information to support situation awareness and crew coordination. The GVDS, by supporting monitoring of key parameters and displaying alarm information, aids in understanding of plant parameter status including emergency operating procedure entry conditions.

Alarm overview information is also presented in a central location in the NCR on or near the GVDS, and detailed alarm information is accessible at each user workstation.

An emergency communications area is provided with indications for monitoring plant conditions, and contains space for up to two people, communications equipment, and administrative tasks. The emergency communications area is located and designed to minimize disturbance of the operating crew.

The NCR contains HSIs to support performance of fire protection system monitoring tasks.

The NCR also includes shelving, an area to store procedures, and printers. There are storage areas provided for PPE (including self-contained breathing apparatuses) and survival supplies within or easily accessible from the NCR.

7.3 Nuclear Island Control Room Adjacent Areas

7.3.1 Shift Manager Office

The shift manager office is within the NCR habitability boundary. To maintain awareness and oversight, the shift manager office includes a window providing line-of-sight into the NCR.

The shift manager office contains a desk workspace designed for seated use and the desk area is large enough to accommodate one seated person (the shift manager) and space to support the equipment and task needs of the shift manager, including communications equipment, administrative tasks, and a conference table.

7.3.2 Restroom

A restroom is provided within the NCR habitability area/isolation boundary for the purpose of allowing watch-team personnel to visit the facility without leaving the NCR habitability area.

7.4 Remote Shutdown Facility

7.4.1 Access

Consistent with IEC 60965:2016 (Reference 5) and IAEA SSR-2/1 (Reference 3), a qualified access path is available so that, under required emergency conditions, the operations staff can safely leave the NCR and reach the necessary RSF workstations.

7.4.2 Remote Shutdown Facility Usage

The RSF is a collection of equipment, or workstations, used to monitor the safe shutdown of the plant when the NCR is no longer available or habitable.

Equipment manipulations required post-event are performed locally (e.g., tripping breakers, adjusting dampers manually), if required.

As such, the RSF is representative of a collection of remote shutdown functions, the physical location of which may be decentralized and combined with other building spaces, as long as the locations collectively meet the requirements for the RSF.

7.4.3 Staffing and User Task Support Needs

The following roles have workstations designed to support the specific information, communication, and work coordination needs for that role:

- Control room supervisor
- NI operator

Workstations contain indications for monitoring and space for procedures and communications equipment. An emergency communications area is provided with indications for monitoring plant conditions and contains space for communications equipment and administrative tasks.

The control room supervisor work area and the communications work area provide space for the shift manager, as needed.

The layout of the instrumentation and the mode of presentation at the RSF provides the operating staff with adequate information to assess the plant state and to supervise the shutdown of the reactor, long-term cooling of the reactor core, and confinement of radioactive substances.

To reduce the likelihood of human errors, the layout and HSI in the RSF matches the available subsections of the NCR to the extent applicable and practicable, with differences driven by different purpose and user task needs.

7.5 Local Controls

Having indications at the control panels in the field helps with the assessment of plant conditions, and therefore local control interfaces are provided where appropriate and include the equipment necessary to support task performance.

7.5.1 Local Refueling Controls

Local manual controls are provided near the refueling machines and are located in a manner that supports good visibility for the task. Provision of a centralized local refueling control station is conducive to deliberate, focused operation of the refueling machines, including the in-vessel transfer machine.

7.6 Other

The areas addressed in Sections 7.6.1, 7.6.2, and 7.6.3 are included for consideration of their coordination with and effect on NI operations. Detailed descriptions of the use, staffing, and user task support for these work areas are outside the scope of this document, the focus of which is NI operations.

7.6.1 Energy Island Control Area

The EI operator in the EI control area performs duties in coordination with the NI operations staff to ensure the EI is ready to perform actions in support of the NI. The EI control area is designed to minimize distractions, such as EI alarms and indications not relevant to plant safety, to the NI operations staff during critical operations.

7.6.2 Fuel Handling Control Room

The FH control room is the primary work area for control and coordination of fuel and core component maneuvers during NI refueling periods and for new fuel receipt and spent fuel campaigns while the nuclear plant is online. The FH control room is anticipated to be the central control station for all FH equipment.

During refueling, FH control room operators and technicians perform duties in coordination with the NCR to ensure plant level permissives and interlocks to the FH control system are satisfied to ensure safe operation of the in-vessel FH system. During spent FH, whether online or offline, the FH control room coordinates with the NCR personnel to ensure that there are no abnormal radiological responses to FH activities.

The FH control room normally is continuously staffed by at least one operator during any fuel maneuvering evolutions.

7.6.3 Technical Support Center

The Technical Support Center (TSC) is an on-site facility that provides plant management and technical support to the reactor operating personnel in the NCR during emergency conditions. The TSC functions to relieve the ROs of peripheral duties and communications not directly related to reactor control, helping to prevent congestion in the NCR during emergencies.

During an emergency, the TSC is the primary communications center for the plant, providing communication capabilities with the NCR and other emergency response facility functional areas. The TSC houses technical data displays and plant records to assist in the detailed analysis and diagnosis of abnormal plant conditions.

Personnel in the TSC assist in the management and control of plant emergency response capabilities to assist control room personnel, mitigate the consequences of an accident, and respond quickly to abnormal operating conditions.

The TSC may also be used during normal operations for shift technical supervision and plant operations and maintenance analysis functions.

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