December 29, 2016 Docket: PROJ0769

U.S. Nuclear Regulatory Commission
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SUBJECT: NuScale Power, LLC Submittal of Third Set of Human Factors Engineering Documentation for Design Certification Application

REFERENCES:
1. Letter from Thomas A. Bergman (NuScale) to U.S. Nuclear Regulatory Commission, "NuScale Power, LLC Submittal of Response to NRC's Letter, 'NuScale Control Room Configuration and Staffing Levels,' January 14, 2016," dated April 8, 2016 (ML16099A270)
2. NRC Table, "Human Factors Engineering Documentation for NuScale Design Certification Application Submittal," dated April 11, 2016 (ML16034A181)

In a letter dated April 8, 2016 (Reference 1), NuScale Power, LLC (NuScale) proposed, in part, the scope of human factors engineering (HFE) information that it planned to submit as part of NuScale's design certification application (DCA). The proposed documentation scope included a list of HFE results summary reports and revised implementation plans. The U.S. Nuclear Regulatory Commission (NRC) confirmed the documentation scope in a table dated April 11, 2016 (Reference 2). In addition to the implementation plans and results summary reports listed Reference 1, NuScale planned to submit, prior to or at the time of DCA submittal, documents describing the concept of operations, control room staffing plan validation methodology and results, and human-system interface style guide to support the DCA.

The purpose of this letter is to forward the following documents to the NRC as the third of six sets of submittals:

1) Proprietary and non-proprietary versions of Human Factors Verification and Validation Implementation Plan, RP-0914-8543-P, Revision 2
2) Proprietary and non-proprietary versions of Human-System Interface Design Results Summary Report, RP-0316-17619, Revision 0
3) Proprietary and non-proprietary versions of Concept of Operations, RP-0215-10815, Revision 2
4) Non-proprietary version of Human Factors Engineering Design Implemenation Implementation Plan, RP-0914-8544, Revision 1

Enclosures 1 through 3 contain the proprietary versions of the first three documents above. Enclosures 4 through 6 contain the non-proprietary versions of the above documents. NuScale requests that the proprietary versions be withheld from public disclosure in accordance with the requirements of 10 CFR § 2.390. The enclosed affidavit (Enclosure 8) supports this request.

This letter makes no regulatory commitments and no revisions to any existing regulatory commitments.

Please feel free to contact Steve Mirsky at 240-833-3001 or at smirsky@nuscalepower.com if you have any questions.

Sincerely,

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Enclosure 1: Human Factors Verification and Validation Implementation Plan, RP-0914-8543-P, Revision 2, proprietary version
Enclosure 2: Human-System Interface Design Results Summary Report, RP-0316-17619-P, Revision 0, proprietary version
Enclosure 3: Concepts of Operations, RP-0215-10815-P, Revision 2, proprietary version
Enclosure 4: Human Factors Verification and Validation Implementation Plan, RP-0914-8543-NP, Revision 2, non-proprietary version
Enclosure 5: Human-System Interface Design Results Summary Report, RP-0316-17619-NP, Revision 0, non-proprietary version
Enclosure 6: Concepts of Operations, RP-0215-10815-NP, Revision 2, non-proprietary version
Enclosure 7: Human Factors Engineering Design Implementation Implementation Plan, RP-0914-8544-NP, Revision 1, non-proprietary version
Enclosure 8: Affidavit AF-1216-52041

Enclosure 1:

Human Factors Verification and Validation Implementation Plan, RP-0914-8543-P, Revision 2, proprietary version

Enclosure 2:

Human-System Interface Design Results Summary Report, RP-0316-17619-P, Revision 0, proprietary version

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Enclosure 3:

Concepts of Operations, RP-0215-10815-P, Revision 2, proprietary version

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Enclosure 4:

Human Factors Verification and Validation Implementation Plan, RP-0914-8543-NP, Revision 2, non-proprietary version

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Human Factors Verification and Validation Implementation Plan

12/02/2016

Revision 2

Docket: PROJ0769

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Department of Energy Acknowledgement and Disclaimer

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Abstract

Human factors verification and validation is a critical element of the human factors engineering (HFE) program that performs evaluations to verify that the HFE design conforms to HFE design principles and that it enables plant personnel to successfully and reliably perform their tasks to assure plant safety and operational goals. Human engineering discrepancies are identified and resolved during the verification and validation process.

This implementation plan describes the methodology for conducting the evaluations and identifying and resolving human engineering discrepancies. The methodology described is consistent with the applicable provisions of Section 11 of NUREG-0711, Revision 3.

Executive Summary

The human factors verification and validation (V&V) element of the human factors engineering (HFE) program consists of the following four major activities:

- sampling of operational conditions
- design verification
- integrated system validation
- identifying and resolving human engineering discrepancies

Sampling of operational conditions identifies the conditions that are representative of the events that may be encountered during plant operation, conditions that reflect the characteristics that may contribute to variations in system performance, and conditions that consider the safety significance of the human-system interfaces (HSIs). These identified operational conditions are used in HSI inventory and characterization, HSI task support verification, HFE design verification, and integrated system validation.

The HSI inventory and characterization accurately describes all HSI displays, controls, and related equipment lying within the scope defined by the sampling of operational conditions. The HSI task support verification confirms that the HSIs provide the alarms, information, controls, and support needed for personnel to perform their tasks as defined by the task analysis. HFE design verification confirms that the design of the HSIs conform to HFE guidelines. Integrated system validation verifies, using performance-based tests, that the integrated system design (i.e., hardware, software, procedures, and personnel elements) supports the safe operation of the plant.

Human engineering discrepancies (HEDs) are identified during the V&V process. HED resolution may be performed iteratively. That is, the identified HEDs are evaluated and resolved appropriately during one V&V activity before conducting other V&V activities. The preferred order of the process is HSI inventory and characterization, HSI task support verification, HFE design verification, and integrated system validation, although iteration may be needed.

1.0 Introduction

1.1 Purpose

This document provides the human factors verification and validation (V&V) implementation plan (IP) for the NuScale Power, LLC (NuScale) plant human-system interface (HSI) design. The HSI design includes the hardware, software, and personnel elements used to operate a NuScale plant.

The NuScale human factors V&V program confirms that the HSI design

- conforms to the specified design.
- conforms to appropriate design criteria.
- performs within acceptable limits under analyzed operating modes and conditions.
- provides the complete set of alarms, controls, indications, and procedures needed to support the personnel tasks as identified in the task analysis (TA).
- adequately supports plant personnel in the safe and reliable operation of the plant.

1.2 Scope

This IP describes the methodology for conducting the four major activities of the human factors V&V element (sampling of operational conditions, design verification, integrated system validation (ISV), and human engineering discrepancy (HED) resolution), including:

- identification of sampling dimensions and scenarios used for validation of the HSI
- human-system interface inventory and characterization
- the criteria used for task support verification and human factors engineering (HFE) design verification
- selection and training of the Validation Team
- determination of validation test objectives
- use of the main control room (MCR) test bed for validation
- selection and training of personnel used as operating crews (i.e. plant personnel)
- scenario selection and definition for the validation
- performance measures to be used in the validation
- design of testing
- data analysis methods applied to validation data
- validation of procedures
- guidance for initiation and evaluation of HEDs

This IP provides a description of the methodology for the identification of scenarios for the ISV. The V&V results summary report (RSR) will provide the information as discussed in Section 6.0. A detailed ISV test report will be developed which supports the findings documented in the V&V RSR; both documents will be submitted to the NRC.

The V&V RSR will also confirm and document that the human factors ISV scope includes the alarms, controls, indications, and procedures for the HFE program.

The HFE program scope is described in the Human Factors Engineering Program Management Plan (Reference 8.2.1). Sampling dimensions with regard to locations, HSIs, conditions, types of tasks, and situational factors are described in Section 2.1.

1.3 Abbreviations and Definitions

Table 1-1. Abbreviations

Abbreviation	Definition
ADDIE	analysis, design, development, implementation, and evaluation
HED	human engineering discrepancy
HFE	human factors engineering
HFEITS	human factors engineering issue tracking system
HSI	human-system interface
I&C	instrumentation & control
IHA	important human action
IP	implementation plan
ISV	integrated system validation
MCR	main control room
PRA	probabilistic risk assessment
RSR	results summary report
SA	situation awareness
SME	subject matter expert
SOC	sampling of operational conditions
TA	task analysis
V&V	verification & validation

Table 1-2. Definitions

Term	Definition
Embedded procedure	{{ }}2(a),(c)
Human Factors Engineering Design Team	Generic term for the Plant Operations organization which consists of Operators, Human Factor Engineers, and Simulator Developers. The HFE Design Team does not include Plant Personnel. The HFE Design Team is responsible for the human factors engineering associated with the NuScale design. Also referred to as the design team.
Human System Interface	The human-system interface (HSI) is that part of the system through which personnel interact to perform their functions and tasks. In this document, "system" refers to a nuclear power plant. Major HSIs include alarms, information displays, controls, and procedures. Use of HSIs can be influenced directly by factors such as, (1) the organization of HSIs into workstations (e.g., consoles and panels) (2) the arrangement of workstations and supporting equipment into facilities such as a main control room, remote shutdown station, local control station, technical support center, and emergency operations facility and (3) the environmental conditions in which the HSIs are used, including temperature, humidity, ventilation, illumination, and noise. HSI use can also be affected indirectly by other aspects of plant design and operation such as crew training, shift schedules, work practices, and management and organizational factors.
Plant Personnel	Operating crew members participating in the ISV. Plant personnel are not part of the HFE Design Team or Validation Team.
Simulator Operator	Person responsible for running the simulator during design, training, and testing. During training and testing, simulator operators should keep track of directions given to nonlicensed operators (NLOs) and other personnel simulated outside the control room. Simulator operators role play as personnel outside the control room and may only provide data that is allowed per the applicable scenario or training guide. Simulator operators may answer questions asked by the crew but should not lead them to the correct answer or diagnosis. Simulator operators are also referred to as “booth operators”.
Simulator Review Board	The Simulator Review Board reviews the results of simulator testing and compares them to analysis and engineering calculations to certify that the simulator reflects the plant design. This board consists of representatives from Safety Analysis, probabilistic risk assessment (PRA), engineering, and operations. Their review is focused on realism to the operator and model validity.
Validation Team	{{ }}2(a),(c)

Term	Definition
VISION	The VISION® Developer application is a relational database that is used to store the FRA/FA, task analysis, staffing and qualifications analysis, development of human-system interfaces (HSI), procedures, and training data. In this document it may be referred to as the "FRA/FA & TA database" or "database".

2.0 Sampling of Operational Conditions and Scenario Development

The purpose of sampling of operational conditions (SOC) is to identify a broad and representative range of operating conditions to be sampled during the HSI inventory and characterization (see Section 3.1), task support verification (see Section 3.2), HFE design verification (see Section 3.3), and ISV testing (see Section 4.0). The sample is deemed representative if the sample's safety significance, risk significance, and challenges to the operating crew are considered to be within the range of events that the operators could encounter during the plant life cycle.

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2.1 Sampling Dimensions

A range of plant conditions, personnel tasks, and situational factors is considered within the sampling dimensions included in Section 11.4.1 of Human Factors Engineering Program Review Model, NUREG-0711, Rev. 3 (Reference 8.1.1) as applicable to the NuScale design.

NuScale operates up to 12 reactors from a single control room and utilizes a digital control system and relies heavily on automation and computer-based procedures. The sampling dimensions include normal operational events, transients and accidents. Due to the increased use of digital technology in the NuScale control room, scenarios will specifically provide an emphasis on instrumentation and control (I&C) and HSI failures as well as degraded conditions.

Scenario development goals are written to ensure the scenarios are comprehensive, and when taken together, cover aspects of all sampling dimensions relevant to the NuScale design.

2.2 Identification of Scenarios

Members of the NuScale HFE Team develop the ISV scenarios using multiple sampling dimensions to accomplish the goals and set the conditions to be included in each scenario based on the SOC.

Biases for individual dimensions are possible, but collectively, the scenarios avoid bias by representing scenarios that

- have both positive and negative outcomes
- require varying degrees of administrative burden to run (test bed set-up, instructor input)
- minimize the use of well-known and well-structured sequences (i.e., textbook design-basis accident mitigation)

During identification of scenarios for ISV, the HFE Design Team develops a table to compare the SOC criteria in each scenario; the comparison table helps assure that representative SOC criteria are addressed by the composite set of scenarios. This comparison table is used to document the bases for assurance that the selected scenarios are representative of expected operational conditions as discussed in Section 6.0.

The ISV scenarios are then reviewed by the appropriate SMEs and approved by operations management. Upon approval, the ISV scenarios and test plan will be available for review or audit by the NRC sufficiently before the conduct of ISV so that comments or concerns can be adequately addressed prior to commencing ISV.

2.2.1 Scenario Security

The following scenario security steps are maintained throughout the ISV entire development and testing process.

- The scenario descriptions and collection of tasks are stored in VISION in a separate work area with access only granted to the scenario and testing developers.
- The selected operating crew member participants (Plant Personnel) are not allowed to review documents associated with the completed scenarios (i.e., scenario guides).
- Printed copies of scenario information are destroyed or placed in a secure location when not in use.

2.3 Scenario Definition

The scenarios used for design verification and ISV testing are selected during the SOC and scenario development process. Scenarios are run in the test bed to validate performance of the integrated system (i.e., hardware, software, and personnel elements) and ensure the design is consistent with the objective. The defined scenarios are designed to involve major plant evolutions or transients, reinforce team concepts, and identify the role each individual plays within the team. Tasks performed by operators remote from the MCR are modeled in the ISV scenario to realistically simulate effects on personnel performance due to potentially harsh environments. Effects such as additional time to don protective clothing, set up of radiological access control areas, and employment of damage control, emergency, or temporary equipment are described in scenarios by use of time constraints/additions.

The NuScale ISV scenarios are developed in a systematic manner and include all applicable test attributes:

- a synopsis
- objectives
- initial condition of the entire plant
- specific initial conditions pertinent to commencement of the scenario
- a timeline of events to be run including initiating conditions where appropriate

- critical tasks to be conducted
- workplace factors (e.g., environmental conditions)
- any material or knowledge-based needs to support the task to be tested
- staffing level
- where specific types of communications are necessary (e.g., an event notification to regulators via dedicated telephone line) details of that expected communication content
- scripted responses for test personnel (both in and out of the MCR)
- data to be collected by observers/instructors (rating scales for administrators are included where appropriate)
- pass/fail criteria for any part of the scenario
- initial test bed set up
- specific criteria for terminating the scenario

The ISV scenarios are developed to be representative of the range of events that could be encountered during the plant’s operation, determined by SOC as described in Section 2.1. Scenarios developed by the HFE Design Team that lead to only positive outcomes, scenarios that are easy to conduct, and scenarios that are well-structured and often practiced are not selected. Scenarios are selected to confront the operating crew with challenging normal conditions and abnormal events containing multiple and unanticipated failures.

Test objectives are discussed in Section 4.2. An individual scenario cannot address all test objectives, but the aggregate ISV includes testing of all objectives. Each scenario tests some portion of the HSI for primary actions (control and verification via the plant response) and secondary actions (navigating the HSI for monitoring of other plant parameters); communication equipment is also verified during scenarios.

3.0 Design Verification Methodology

The design verification activity is accomplished during two phases of the V&V process; Phase I (Figure 3-1) is HSI inventory and characterization, and Phase II (Figure 3-2) is HSI task support verification and HFE design verification. The flow charts for each activity are shown below followed by a discussion of each phase.

ISV testing can involve hundreds or thousands of individual HSIs, and it is impractical and unnecessary to review all of them. Therefore, NuScale employs a sampling strategy to guide the selection of HSIs to review.

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Figure 3-1. Phase I: Human-system interface inventory and characterization flow chart

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Figure 3-2. Phase II: HSI task support verification & HFE design verification flow chart

NOTE: HED identification and resolution details are discussed in Section 5.0.

3.1 Human-System Interface Inventory and Characterization

The objective of the HSI inventory and characterization is to accurately describe the set of selected HSI displays, controls, and related equipment within the scope defined by the SOC. Automation and the associated embedded procedures are also included in the scope of HSI inventory and characterization. The HFE Design Team follows a process that includes verifying all HSI elements against the TA and provides a feedback loop back to the HSI input block as shown in Figure 3-1.

3.1.1 Human-System Interface Inventory

The list of HSI inventory is generated during TA and developed during Phase I of the HSI design process. The TA defines the inventory and characterization for the alarms, controls, indications, and procedures needed to execute operator tasks for normal and abnormal plant conditions including manual tasks, automation support tasks, and automation monitoring tasks. In preparation for characterization, the output of TA and HSI design is compared to the HSIs that personnel will need for the tasks in the scenarios developed for SOC. Characterization defines the functionality of each HSI.

3.1.2 Human-System Interface Characterization

Characterization defines the functionality of each HSI selected for verification. HSI design documents such as equipment lists, design specifications, and input/output lists are produced during HSI design. Characteristics of each HSI component are included in the associated design document which includes the minimum set of information:

- a unique equipment identification code that links the HSI component to the associated plant system or subsystem
- associated personnel functions/sub-functions
- type of HSI (indication, control, alarm, procedure, hard-wired, screen-based, etc.)
- HSI characteristics and functionality (unit of measure, accuracy of variable/parameter, format, continuous or discrete (if a control), system response time, etc.)
- HSI control characteristics and functionality (modes, accuracy, precision, format)
- method of use and associated user-aids
- physical or virtual (i.e., on a screen) location of HSI

3.1.3 Inventory Verification

Inventory verification confirms the visual aspects (alarms, controls, indications, embedded procedures and the means of navigation between elements) of the HSI, including conformance to the NuScale Human System Interface Style Guide (Reference 8.2.2) during HFE design verification. This also includes verification of other HSI characteristics such as tag number, location, piping, and instrument diagram or logic diagram implementation.

NuScale HSI navigation and notifications are part of the spatially dedicated continuously visible main navigation bar. These elements do not need to be verified for every system HSI developed. These global elements are verified once during this verification phase for all selected HSI following the process used during staffing plan validation.

3.2 Human-System Interface Task Support Verification

The purpose of HSI task support verification is to verify the HSIs support the task requirements on the selected HSI. The assessment verifies that HSIs provide the alarms, controls, indications, and task support for personnel to perform their tasks as defined by the TA. For HSI task support verification related to performance (e.g., accuracy and dynamic response), the validation test bed is used. The HSI task support verification process is shown in Figure 3-2.

3.2.1 HSI Task Support Verification Criteria

The task support verification is based on the TA results that define the inventory and characterization for the alarms, controls, indications, procedures, automation, and task support needed to successfully execute operator tasks.

3.2.2 HSI Task Support Evaluation Methodology

The HFE Design Team conducts HSI task support verification using a verification process to control bias and improve consistency. The task support verification process entails a detailed comparison of the personnel task requirements identified by the TA (i.e., the planned attributes) with the alarms, controls, indications, procedures, automation, and task support in the HSI inventory and characterization (i.e., the actual attributes). The HFE Design Team follows a process that provides a Retest step if needed as shown in Figure 3-2.

Results of the task support verification are based on the criterion that the information, control, and functional characteristics to support the task requirements identified during TA are present in the HSI that is being verified for the task. Results are documented for each task in the V&V RSR (see Section 6.0) once the V&V activities are complete.

3.3 Human Factors Engineering Design Verification

The HFE design verification is conducted to confirm that HSI characteristics conform to HFE guidelines as represented in the style guide. The style guide consists of procedures for use, general considerations, and system-specific guidance for screen-based HSIs (the term system-specific applies to plant systems as well as HSI systems). The HFE design verification process is shown in Figure 3-2.

3.3.1 Verification Criteria

The criteria for HFE design verification is provided by the HSI style guide. The style guide includes procedural guidance for determining appropriate design criteria when the style guide does not apply to the characteristics of the HSI component being designed.

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3.3.2 Design Verification Evaluation Methodology

HFE design verification is conducted in accordance with a written process to assure consistency of results and to control bias. The design verification phase for all selected HSI follows a process that provides a Retest step if needed as shown in Figure 3-2.

Procedures describing HFE design verification include

- checklists and guidelines for comparison of the HFE design criteria (style guide) to HSI components (e.g., alarms, controls, indications, procedures, navigation aids)
- a description of the means of comparing HFE design criteria to HSI components in the context of the various environmental conditions or locations of those HSIs (e.g., noise, lighting, ambient temperature and humidity)
- guidelines for determining whether the HSI is acceptable or discrepant based on the associated HFE design criteria
- methods for preparation and review of the HFE design verification as well as course of action when reviewers do not agree on the results

- design verification HEDs are generated for HSIs that do not meet the HFE design criteria completely

4.0 Integrated System Validation

The ISV is the process by which an integrated system design (i.e., hardware, software, and personnel elements) is evaluated using performance-based tests to determine whether it acceptably supports safe operation of the plant. The ISV is undertaken only after HEDs that were identified in the upstream process, including design verification, have been resolved and the resulting changes implemented.

Scenarios are developed using the guidance described in the implementing procedures. Performance measures used for assessing the results of an ISV are summarized in Section 4.5 and further described in implementing procedures.

4.1 Validation Team

Validation team members can be selected from the HFE Design Team. There is very low risk of impact to the validity of the ISV results. Objective performance measures and success criteria are developed as part of the methodology. The methodology including the detailed scenarios and ISV test plan are available for audit well in advance of the conduct of the ISV. The Validation Team members are trained and qualified to conduct the ISV in an objective and unbiased manner. The conduct of the ISV is scheduled such that all or any portion is available for audit. A detailed ISV test report is developed which supports the findings documented in the V&V RSR; both documents will be submitted to the NRC. The HFE Design Team developing and conducting the ISV is analogous to a commercial nuclear plant's Training Department developing and conducting an NRC license exam or annual requalification exam.

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}}2(a),(c) The observers are trained and qualified using the NuScale training program.

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4.2 Test Objectives

The objectives of the ISV are to validate

- the acceptability of the shift staffing, the assignment of tasks to operating crew members, and crew coordination within the control room, between the control room and local control stations and support centers, and with individuals performing tasks locally. This should encompass validating minimum shift staffing levels, nominal levels, higher levels, and shift turnover.
- that the design has adequate capability for alerting, informing, controlling, and feedback such that personnel tasks are successfully completed during normal plant evolutions, transients, design-basis accidents, and also under selected risk significant events beyond-design basis, as defined by the SOC.
- that specific personnel tasks can be accomplished within the time and performance criteria, with effective situational awareness, and acceptable workload levels that balance vigilance and personnel burden.
- that the HSIs minimize personnel error and ensure error detection and recovery capability when errors occur.
- the assumptions about performance on important human actions (IHAs).

4.3 Validation Test Beds

The principal validation test bed for the ISV is the control room simulator. The fidelity of the validation test bed's models and HSI are verified to represent the current, as-designed NuScale plant prior to use for the validation.

The test bed model is made up of four modeling software packages, all working from current NuScale designs. Together, they provide a high level of fluid and reactivity modeling. Precisely modeling the predicted behavior of the reactor core, thermodynamic performance, balance of plant, and electrical system design is desired as NuScale does not have a comparison reference plant. All 12 units are simultaneously and independently modeled, but they all correctly share systems that provide input for multiple units.

The test bed is validated against the seven criteria described in Section 11.4.3.3 of Reference 8.1.1: interface completeness, interface physical fidelity, interface functional fidelity, environment fidelity, data completeness fidelity, data content fidelity, and data dynamics fidelity. These criteria are further discussed in sections 4.3.1 thru 4.3.7 below.

The validation test bed attempts to accurately simulate a NuScale plant MCR environment. Where this is not achievable by the test bed (e.g. room temperature and lighting during a loss of all AC power), an exception is taken and documented in the V&V RSR discussed in Section 6.0. If necessary, changes are also made to the ISV test procedure to reflect the alternate test bed configuration. In some limited cases, the V&V team may consider the test bed discrepancies to affect specific aspects of the validation results. If so, an HED is generated to document the discrepancy and the concern. The

HED is resolved in accordance with the HED resolution process described in Section 5.0.

4.3.1 Interface Completeness

The test bed represents a complete and integrated system with HSI and procedures not specifically required in the test scenarios. (e.g., alternate procedures). The test bed further represents interfaces with the RSS and local control stations (i.e., communications) to provide an integrated system.

4.3.2 Interface Physical Fidelity

High physical fidelity in the HSI and procedures is represented, including presentation of alarms, displays, controls, procedures, automation, job aids, communications, interface management tools, layout, and spatial relationships. The test bed is a replica in form, appearance, and layout of the NuScale MCR design.

4.3.3 Interface Functional Fidelity

High functional fidelity in the HSI, procedures, and automation is represented so that the HSI functions are available and the HSI component modes of operation, types of feedback, and dynamic response characteristics operate in the same way as the actual plant.

4.3.4 Environmental Fidelity

The test bed is representative of the actual NuScale plant with regard to environmental features such as lighting, noise, temperature, humidity, and ventilation characteristics. In cases where the test bed cannot accurately simulate the environment, the ISV captures human factors engineering issue tracking system (HFEITS) entries for evaluation and resolution.

4.3.5 Data Completeness Fidelity

In the test bed, information and data provided to personnel represent the complete set of plant systems monitored and controlled from that facility.

4.3.6 Data Content Fidelity

The test bed represents a high degree of data content fidelity. The alarms, controls, indications, procedures, and automation presented are based on an underlying plant model that accurately reflects the engineering design of the NuScale plant. The model also accurately provides input to the HSI, such that the information matches what is presented during operations.

4.3.7 Data Dynamics Fidelity

The test bed represents a high degree of data dynamic fidelity. The plant model provides input to the HSI in a manner such that information flow and control responses occur accurately and in a correct response time. Information is provided to personnel with the same anticipated delays as would occur in the plant.

4.3.8 Remote Human-System Interfaces Containing Important Human Actions

NuScale has no IHAs that are conducted outside of the MCR. In the event that a remote IHA is determined in a later design stage, the test bed uses mockups to verify human performance requirements for IHAs conducted at HSIs remote from the MCR. The simulation or mockup considers, for example, transit times, use of personal protective equipment, and delays associated with the need for operator precision (self-checking).

4.3.9 Test Bed Conformance

The test bed is verified to conform to required characteristics before validation tests are conducted.

4.4 Plant Personnel

Individual operating crews participating in the ISV may be previously licensed commercial reactor or senior reactor operators, operators with Navy nuclear experience, or design engineering staff members familiar with the NuScale Power plant design. The personnel participating in ISV are trained, qualified, and are assigned to roles commensurate with their experience, skill, and knowledge level.

Personnel who constitute the ISV operating crews are not part of the HFE V&V team or HFE design team. Operating crew makeup is not varied from scenario to scenario and remains consistent throughout the validation (i.e., crew members are not rotated between operating crews).

To control crew bias, individual crew members are distributed across crews with consideration for:

- age distribution
- gender distribution
- education level distribution
- experience distribution; generally industry operators have a minimum of one year of experience, while engineers have a minimum of two years' experience in addition to NuScale plant systems training

Operating crew size for the validation tests includes a range of expected sizes to ensure that the HSI supports operations and event management. This range includes the minimum operating crew, nominal levels, and higher levels as defined during the staffing and qualifications program element NuScale Human Factors Engineering Staffing and Qualifications Results Summary Report (Reference 8.2.3) for a range of plant operating modes. The crew size for each scenario is identified in the ISV test procedure, and scenarios are not repeated with different crew sizes.

The ISV includes at least one scenario with more than minimum crew staffing defined in Reference 8.2.3 (e.g., additional licensed operators to complete a complex evolution) to simulate times of high control-room traffic and distractions and high environmental loading. The roles of the additional personnel and their interaction with the operating crew are determined by the scenario developers based on meeting all the test objectives and goals and by applying the SOC criteria.

4.5 Performance Measurement

Performance measures for ISV are hierarchical and include measures of plant performance, personnel task performance, situation awareness (SA), cognitive and physical workload, and anthropometric or physiological factors. Both pass or fail and diagnostic measures are applied.

4.5.1 Types of Performance Measures

4.5.1.1 Plant Performance Measures

Plant performance resulting from operator action or inaction includes plant process data (e.g., temperature, pressure) and component status (e.g., on/off; open/closed) as a function of time at as many locations in the plant simulation as is possible. These data are obtained from the entire plant: nuclear, fluid, structural, and electrical components. Any component that provides plant process data or component status in the plant is simulated with appropriate fidelity. The test bed has the ability to record all plant process data and component status (including state changes) for the full length of any ISV scenario.

4.5.1.2 Personnel Task Performance Measures

For each scenario, tasks that personnel are required to perform are identified and assessed. Primary and secondary personnel tasks are evaluated.

Primary tasks are those involved with function and task completion including detection, assessment, planning, and response. The level of detail to which primary tasks are measured and performance measures selected are assessed based on the complexity of the task. It may only be necessary to measure time and accuracy for a lower level rule-based task to recognize and respond, while tasks that are knowledge-based (e.g., detection, seeking additional data, making decisions, or taking actions) may entail the use of more detailed performance measures.

Secondary task performance measures reflect the workload associated with HSI manipulations associated with maintaining the overall plant. Test personnel evaluate secondary tasks in conjunction with primary tasks to observe effects on overall performance and workload both at individual and operating crew level.

Personnel task performance measurements are selected to reflect those aspects of the task that are important to system performance and used depending on the particular scenario such as

- time

- accuracy
- frequency
- amount achieved or accomplished
- consumption or quantity used
- subjective report of participants
- behavior categorization by observers

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Objective measures of individual or crew and system performance are also collected during validation scenarios and are used for documenting the performance and future use. They include

- video recordings of operator performance
- alarm history log
- operator control interactions
- plant variable control interactions (resulting from operator controls)
- component status change
- HSI use log (display screen request history and operational history)

The capturing of data using cameras enables NuScale to document the operator's actions as they are performed. With the information archived, it is then available for the life of the design for tracking purposes. The comparison between actual and expected actions is an important test criterion when trying to identify errors of omission and commission. NuScale performs this comparison during the V&V testing process and will maintain a retrievable video library, as a contingency, for instances where observations conflict or actions come into question.

4.5.1.3 Situational Awareness Performance Measures

To measure SA, ISV applies a combination of objective measures along with subjective post-scenario questionnaire methods.

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4.5.1.4 Cognitive and Physical Workload Performance Measures

To measure cognitive workload, the ISV employs the following methods

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4.5.1.5 Anthropometric and Physiological Factor Performance Measures

The primary purpose of anthropometric and physiological performance measures during ISV is to assess those aspects of the design that cannot be evaluated during design verification. Anthropometric and physiological performance measures evaluate how well the HSI supports plant personnel in monitoring and control of the plant. Many of these design aspects are assessed as part of verifying the HFE design. Therefore, the focus is on those areas of the design that only can be addressed by testing the integrated system, e.g., the ability of personnel to effectively use the various controls, displays, workstations, or consoles while performing their tasks. {{

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4.5.2 Performance Measure Information and Validation Criteria

4.5.2.1 Collection Methods

Subjective assessments of the HSI and its impact on performance, including self-ratings of workload, SA, and teamwork, are conducted by test personnel operating crews. Operator feedback on the HSI is collected via post-scenario debriefs and questionnaires. Both types of operator feedback include scale rating questions and open feedback (long answer) questions.

Objective data (e.g., video recording, administrator observations) collected during test scenarios are analyzed to assess impacts of operator actions on plant processes and equipment states. The analysis compares the performance derived from parameters and times collected by the test bed to the evaluation criteria for operator actions and for overall plant process behavior developed for each scenario.

Test observers and administrators document individual assessments of crew performance on a post-scenario observer form immediately after the scenario. {{

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In addition to HSI performance problems, observers and administrators rate technical and teamwork performance on the post-scenario observer form. Crew size sufficiency is rated, and any potential or noticeable HEDs are identified.

Test subjects also document their feedback on a post-scenario test subject form immediately after the scenario. The test subject form is similar to that of the observer and administrator with observations of HSI performance problems, technical and teamwork performance observations, crew size sufficiency ratings, and potential or noticeable HEDs.

The data collected from subjective and objective sources are analyzed by the HFE team to determine the sufficiency of the HFE design.

4.5.2.2 Performance Measure Characteristics and Bases

Performance measures to be observed during ISV contain the characteristics described in Table 4-1.

Table 4-1. Characteristics of performance measures

Characteristic	Meaning
Construct Validity	A measure should represent accurately the aspect of performance it is intended to measure.
Reliability	A measure should be repeatable; i.e., same behavior measured in exactly the same way under identical circumstances should yield the same results.
Sensitivity	A measure's range (scale) and its frequency (how often data are collected) should be appropriate to that aspect of performance being assessed.
Unobtrusiveness	A measure should minimally alter the psychological or physical processes that are being investigated.
Objectivity	A measure should be based on easily observed phenomena.

The basis for inclusion of a performance criterion in the ISV (or a particular scenario within ISV) used to judge acceptability of that criterion is determined during the development of the scenario. Bases for performance criteria are described in Table 4-2.

Table 4-2. Basis for performance criteria

Criteria	Basis Meaning
Requirement	The observed performance of the integrated system is compared with a quantified performance requirement; i.e., the requirements for the performance of systems, subsystems, and personnel are defined through engineering analyses.
Benchmark	The observed performance of the integrated system is compared with a criterion established using a benchmark system, e.g., a current system is predefined as acceptable.

Criteria	Basis Meaning
Norm	The observed performance of the integrated system is compared with a criterion using many predecessor systems (rather than a single benchmark system).
Expert Judgment	The observed performance of the integrated system is compared with a criterion established by subject-matter experts.

Performance measures are designated as pass, fail or diagnostic. Diagnostic is measureable and the criteria include both range and unit of measure.

4.6 Test Design

Test design refers to the process of developing scenarios, test plans, and conducting ISV based on the integrated HSI as described in the preceding sections. The goal of test design is to permit the observation of integrated system performance while minimizing bias.

Once the ISV test plan and scenarios are developed they will be reviewed by the appropriate SMEs and approved by operations management. Upon approval, the ISV scenarios and test plan will be available for review or audit by the NRC sufficiently before the conduct of ISV so that comments or concerns can be adequately addressed prior to commencing ISV.

This section describes characteristics of the test design important to supporting ISV validity.

4.6.1 Scenario Sequencing

Integrated System Validation: Methodology and Review Criteria, NUREG/CR-6393 (Reference 8.1.2), is employed as the standard for selection of crew or scenario order as follows:

- A minimum of two operating crews perform each scenario.
- Crews perform a grouping of scenarios in a different order than other crews.
- When running individual scenarios across multiple crews, the order of the crews is varied when the scenario is changed.

ISV scenarios also contain variable normal operation time prior to introducing events to ensure that operating crews are not pre-tuned to immediate events and actions at the beginning of each scenario or at the same time during each scenario.

4.6.2 Test Procedures

Prior to ISV, detailed test procedures are prepared to manage tests, assure consistency, control test bias, support repeatable results, and focus the test on the specific scenario objectives. The test observers/administrators use the test procedures to set up each scenario, manage the scenario, and analyze the test results. Scenario developers use test procedures to build the scenario set.

ISV test procedures are designed to minimize the introduction of bias by both observer/administrators and operating crews. A standardized scenario template is part of the test procedure. Test procedures include

- scenario order for each crew and order of crews when running a single scenario multiple times
- detailed and standardized instructions for briefing the test participants before each scenario
- specific instructions and criteria for observer/administrators on conduct of scenarios
- scripted questions and responses for observer and administrators acting as plant staff during the scenario
- guidance on when and how to interact with the operating crew when the test bed encounters difficulties
- specification of unique data to be collected and stored (including what, when, and how) (Section 4.5)
- guidance for documenting
  - operating crews and scenario details
  - deviations from the test procedure, test difficulties, significant unusual events
  - collected plant raw data
  - observer and administrator notes
  - post-scenario and final debriefing notes
  - crew questionnaires
  - observer and administrator questionnaires
  - observer and administrator consensus notes
  - video and audio recordings
  - human engineering discrepancies
- post-testing instructions for each operating crew that instruct them not to discuss the scenarios and HSI with others

4.6.3 Training Test Personnel

Prior to starting ISV, observer and administrators are trained and qualified on NuScale plant systems, the HSI, and ISV test procedures. Training consists of both classroom and test bed time. Training goals include

- assuring familiarity with test procedures and scenarios
- reduction of bias and errors that may be introduced by the observers and administrators due to test-based learning, failure to follow the test procedure, or incorrect interaction with the operating crew

- use of the test procedure
- documentation needs for each test, including
  - where the test did not follow the scenario
  - problems that occur during testing, even if they were due to an oversight or error of those conducting the test
- the necessity of limiting observer and administrator interaction with test personnel to that which is in the scenario description
- how to conduct post-scenario debriefings
- familiarity with HFE data collection tools and techniques
- familiarity with observation techniques, goals, and responsibilities specific to each observer's role

4.6.4 Training Participants

Test_participants undergo training similar to that which plant operators receive including conduct of operations, plant systems, HSI, plant events, and operating procedures. Test participants are not trained specifically on the scenarios in which they will participate.

To assure near-asymptotic performance and a consistent level of proficiency between individuals making up the operating crews, only participants who have successfully completed the training program and have reached an acceptable level of proficiency are considered to be qualified for operating crew assignment.

4.6.5 Pilot Testing

A test operating crew, which does not participate in ISV, conducts a pilot test (a pre-validation test) to

- assess the adequacy of test design, performance measures, and data-collection methods
- give the observers and administrators experience in running the test
- ensure that the ISV runs smoothly and correctly

4.7 Data Analysis and Human Engineering Discrepancy Identification

Test data are analyzed using both quantitative and qualitative methods. The analysis identifies the relationship between the observed and measured performance and the established acceptance criteria described in Section 4.5.2. Data are analyzed for each scenario across multiple trials. The method of analysis, consistency of measure assessing performance, and criteria used to determine successful performance for a given scenario is determined by the HFE Design Team..

HED identification and resolution details are discussed in Section 5.0

4.8 Validation Conclusions

ISV conclusions are based on

- a comprehensive testing program performed by an independent ISV team using test procedures covering the scope described above
- a high-fidelity test platform representative of the actual system, model, and HSI in aspects important to the integrated system's performance; variable aspects of the integrated system are adequately sampled
- acceptance criteria are measurable, reflect good operational practices, and are representative of important aspects of performance
- test design minimizes bias or confounding effects so as not to affect the validity of the results
- statistical conclusions, where possible, are based on convergence of multiple measures
- specific pass and fail performance criteria documented as HEDs also identify the extent of the issue

ISV conclusions documented in the V&V results summary report include

- the statistical and logical bases for determining that performance of the integrated system is acceptable
- the limitations in identifying possible effects on validation conclusions and that the impact on the design integration HFE program element is considered, including
  - aspects of the tests not well controlled
  - potential differences between the test situation and actual operations such as the absence of productivity-safety conflicts
  - differences between test platform design and the as-built NuScale plant

5.0 Human Engineering Discrepancy Resolution

Human engineering discrepancies (HEDs) are identified, documented, and resolved throughout the verification and validation process. NuScale begins to record HEDs after the completion of staffing plan validation.

HEDs may not always be resolved; HEDs may be found acceptable after an evaluation in the context of the integrated design. The basis for a decision for accepting an HED without change in the integrated design is documented. It may be based on accepted HFE practices, current published HFE literature, trade-off studies, tests, or engineering evaluations. HEDs are identified in the V&V process during

- task support verification (Section 3.2)
- HFE design verification (Section 3.3)
- ISV (Section 4.0)

HFE issues and HEDs are identified and tracked in the HFEITS database. The HFEITS database is available to any member of the HFE team and identification of issues is part of the NuScale corporate culture. The HFEITS database is maintained until fuel load.

A sampling of HEDs found during the V&V process will be discussed in the V&V RSR HED evaluation documentation section and include information on the potential cumulative effects of HEDs observed and samples of HEDs which may have shown an indication of broader issues seen during testing.

5.1 HED Design Solution Implementation

During ISV testing, HEDs are analyzed by the HFEITS team for priority selection and design category placement (e.g., HSI or simulator). Once the HED has been received, a discrepancy entry is created in the HFEITS database and the HED is prioritized as Priority 1, Priority 2, or Priority 3 HEDs according to their importance as follows:

- Priority 1 HEDs have a potential direct or indirect impact on plant safety and are resolved before ISV testing is considered complete. HEDs initiated as a result of a performance measure not being met (pass or fail performance measures) are Priority 1 HEDs. Cross-cutting issues determined through HED analysis or performance measure analysis are also Priority 1 HEDs due to their global impact on the HSI design performance.
- Priority 2 HEDs have a direct or indirect impact on plant performance and operability and are resolved before the plant design is completed.
- Priority 3 HEDs are those that do not fall into Priority 1 or Priority 2. Priority 3 HEDs do not have to be resolved. If resolution of Priority 3 HEDs is determined to be needed, they are resolved during design implementation

The HED is then routed to the appropriate group for resolution. HEDs related to the HSI are sent to the HFE design team, and HEDs related to simulator modeling are sent to the simulator review board. It is possible for HEDs to be routed to both groups.

The HED is then resolved, and the discrepancy entry closed. The HED resolution is reviewed for final closure in the HFEITS database by an HFE Review committee. The HED resolution process is depicted in Figure 5-1.

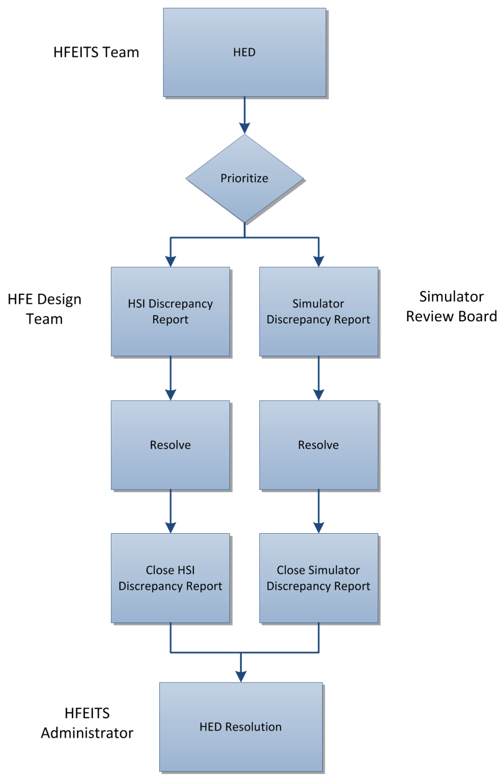

Figure 5-1. Human engineering discrepancy resolution process

5.2 Human Engineering Discrepancy Analysis

HFE V&V HEDs are categorized based on their principal impact on

- personnel tasks and functions
- plant systems
- human-system interface feature
- individual HSI component
- operating procedure

Extent of condition and causal effect across the various HSI design features and functions are assessed as part of the HED process. Extent of condition determination considers

- cumulative or combined effects of multiple HEDs
- human engineering discrepancies that may represent a broader issue

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The broad-reaching testing and number of performance measures to be evaluated limit the ability to perform statistical analyses. Testing of multiple scenarios with multiple crews (generally, each crew will develop a different strategy) makes it impractical to make conclusions based on performance of the population or deviations from a norm. Therefore, observer and administrators, test participants, and the Validation Team evaluate any instance where a performance measure is not met to determine causal factors.

- Design-related deficiencies determined for alarms, controls, indications, and procedures are documented in an HED. Any previous HFE program element may need to be evaluated to resolve the deficiency. The HSI design is not considered validated until an HED initiated by pass/fail measures as a result of ISV is resolved.
- Test-related deficiencies are documented in the HFEITS and may result in changes to the test procedure or scenario definition.

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Data and data-analysis tools (e.g., equations, measures, spreadsheets, expert opinions, resulting HEDs) are documented for subsequent audit and application during design integration and/or human performance monitoring HFE program elements. Individual HFEITS items are maintained as auditable records in the HFEITS database.

6.0 Verification & Validation Results Summary Report

Following completion of all V&V activities, the results will be compiled in an RSR. The RSR will contain

- a matrix of HFE V&V team participants and roles
- human factors engineering V&V results overview and principal findings from design verification
- a sampling of priority 1 HEDs generated from the V&V, the analyses associated with these HEDs, and their resolutions
- human factors engineering V&V execution results
  - verification
    - a description of the application of the verification program
    - verification results based on TA
    - verification results based on the HSI design style guide
    - discussion of HEDs that resulted from the verification, extent of condition, resolution, and any subsequent HSI design changes made prior to validation
    - verification test procedures
    - verification procedure and analysis tools used to draw conclusions and provide assurance that selected scenarios are representative of expected operational conditions (tools may include tables or checklists)
  - validation
    - a description of the application of the validation program
    - validation test procedures
    - integrated system validation procedure, including scenarios
    - a detailed description of the specific scenario sets used in testing including: test instructions, data collection instruments, SOC versus scenario comparison table, and scenario identification summary table
    - data analysis results and validation conclusions, as compared to the minimum set of test objectives
    - a discussion of pass and fail HEDs that resulted from the validation, extent of condition, resolution, and any subsequent HSI design changes, analyses, or retest
    - a discussion of performance improvement measures
    - a discussion of validation results and conclusions that pass/fail criteria have been met

7.0 NUREG-0711 Conformance Evaluation

Table 7-1 indicates where each NUREG-0711, Revision 3 criterion is addressed in this IP.

Table 7-1. Conformance with NUREG-0711

Review Criteria	HFE V&V IP Section No. and paragraph
11.4.1.1 Sampling Dimensions The following sampling dimensions are addressed below: Plant conditions, personnel tasks, and situational factors known to challenge personnel performance. (1) The applicant should include the following plant conditions: • normal operational events including plant startup, shutdown or refueling, and significant changes in operating power • I&C and HSI failures and degraded conditions that encompass: – The I&C system, including the sensor, monitoring, automation and control, and communications subsystems; [e.g., safety-related system logic and control unit, fault tolerant controller, local "field unit" for multiplexer (MUX) system, MUX controller, and a break in MUX line] – common cause failure of the I&C system during a design basis accident (as defined by BTP 7-19) – HSIs including, loss of processing or display capabilities for alarms, displays, controls, and computer-based procedures • transients and accidents, such as: – transients (e.g., turbine trip, loss of off-site power, station blackout, loss of all feedwater, loss of service water, loss of power to selected buses or MCR power supplies, and safety and relief valve transients) – accidents (e.g., main-steam-line break, positive reactivity addition, control rod insertion at power, anticipated transient without scram, and various-sized loss-of coolant accidents) – reactor shutdown and cooldown using the remote shutdown system – reasonable, risk-significant, beyond-design-basis events that should be determined from the plant-specific PRA	Section 2.1, bullet 1

Review Criteria	HFE V&V IP Section No. and paragraph
(2) The applicant should include the following types of personnel tasks: • Important HAs, Systems, and Accident Sequences – The sample should include all important HAs, as determined in Section 7. Additional factors that contribute highly to risk, as defined by the PRA, also should be sampled: – dominant accident sequences – dominant systems (selected through PRA importance measures, such as Risk Achievement Worth or Risk Reduction Worth) • *Manual Initiation of Protective Actions* – The sample should include manual system level actuation of critical safety functions. • *Automatic System Monitoring* – The sample should include situations in which humans must monitor a risk-important automatic system. • *OER-Identified Problematic Tasks* – The sample should include all personnel tasks identified as problematic during the applicant's review of operating experience. • *Range of Procedure Guided Tasks* –The sample should include tasks that are well defined by procedures. Personnel should be able to understand and execute the specified steps as part of their rule-based decision-making. Regulatory Guide 1.33, Appendix A, contains several categories of "typical safety-related activities that should be covered by written procedures." The sample should include appropriate procedures in each category: – administrative procedures – general plant operating procedures – procedures for startup, operation, and shutdown of safety-related systems – procedures for abnormal, off-normal, and alarm conditions – procedures for combating emergencies and other significant events (e.g., reactor accidents, and declaration of emergency-action levels) – procedures for controlling radioactivity – procedures for controlling measuring and test equipment and for surveillance tests, procedures, and calibration – procedures for performing maintenance – chemistry and radiochemical control procedures	Section 2.1, bullet 2

Review Criteria	HFE V&V IP Section No. and paragraph
• *Range of Knowledge-Based Tasks* – The sample should include tasks that are not well defined by detailed procedures. *Additional Information*: A situation may demand knowledge-based decision-making if the procedural rules do not fully address the problem, or when the selection of an appropriate rule is unclear. An example in a pressurized water reactor plant may be the difficulty in diagnosing a steam generator tube rupture (SGTR) with a failure of radiation monitors on the plant's secondary side. This happens because (1) there is no main indication of the rupture (the presence of radiation in secondary side), and (2) the other effects of the rupture (i.e., slight changes in pressures and levels on the primary and secondary sides) may be attributed to other causes. While the operators may use procedures to treat the symptoms of the event, the determination that the cause is a SGTR may call for a situational assessment based on an understanding of the plant's design and the possible combinations of failures that entail the observed symptoms. Errors in rule-based decision-making result from selecting the wrong rule, or incorrectly applying a rule. Errors in knowledge-based decision-making result from mistakes in higher-level cognitive functions, such as judgment, planning, and analysis. The latter are more likely to occur in complex failure events wherein the symptoms do not resemble the typical case, and thus, are not amenable to pre-established rules. • *Range of Human Cognitive Activities* – The sample should include the range of cognitive activities that personnel perform, including: – detecting and monitoring (e.g., of critical safety-function threats) – situation assessment (e.g., interpreting alarms and displays to diagnose faults in plant processes and in automated control and safety systems) – planning responses (e.g., evaluating alternatives to recover from plant failures) response implementation (e.g., in-the-loop control of plant systems, assuming manual control from automatic control systems, and carrying out complicated control actions) – obtaining feedback (e.g., feedback of the success of actions taken) • *Range of Human Interactions* – The sample should include the range of interactions among plant personnel, including tasks performed independently by individual crew members, and those undertaken by a team of crew members. These interactions among plant personnel should include interactions between: – main control room operators (e.g., operations, shift turnover walkdowns) – main control room operators with auxiliary operators and other plant personnel performing tasks locally (e.g. , maintenance or I&C technicians, chemistry technicians) – main control room operators and the TSC and the EOF – main control room operators with plant management, the NRC, and other outside organizations	Section 2.1, bullet 2
(3) The applicant should include the following situational factors or error-	Section 2.1, bullet 3

Review Criteria	HFE V&V IP Section No. and paragraph
forcing contexts known to challenge human performance. It also should include situations specifically designed to create human errors to assess the system's error tolerance, and the ability of personnel to recover from any errors, should these occur, for example: • High-Workload Situations – The sample should include situations where variations in human performance due to high workload and multitasking situations can be assessed. • Varying-Workload Situations – The sample should include situations wherein variations in human performance due to workload transitions can be determined. These include conditions where there is (1) a sudden increase in the number of signals that must be detected and processed after a period in which signals were infrequent, and (2) a rapid reduction in the need for detecting signals and processing demands following a time of high sustained task-demand. • Fatigue Situations – To the extent possible, the sample should include situations that may be associated with fatigue, such as work on backshifts and tasks performed frequently with repetitive actions, such as repeated inputs to a touch screen during plant operations or pulling rods. • Environmental Factors – To the extent possible, the sample should include environmental conditions that may cause human performance to vary, e.g., poor lighting, extreme temperatures, high noise, and simulated radiological contamination.	
11.4.1.2 Identification of Scenarios (1) The applicant should combine the results of the sampling to identify a set of V&V scenarios to guide subsequent analyses. *Additional Information*: A given scenario may combine many of the characteristics identified by sampling of operational conditions.	Section 2.2, all
(2) The applicant should not bias the scenarios by overly representing the following: • scenarios for which only positive outcomes are expected • scenarios that, for ISV, are relatively easy to conduct (i.e., scenarios should not be avoided simply because they are demanding to set up and run on a simulator) • scenarios that, for ISV, are familiar and well structured (e.g., which address familiar systems and failure modes that are highly compatible with plant procedures, such as "textbook" design-basis accidents)	Section 2.2, all

Review Criteria	HFE V&V IP Section No. and paragraph
11.4.1.3 Scenario Definition (1) The applicant should identify operational conditions and scenarios to be used for HSI Task Support Verification, Design Verification, and ISV. The applicant should develop detailed scenarios suitable for use on a full-scope simulator. The level of detail should be comparable to what one would include in a test plan. For each one, the following information should be defined to reasonably assure that important dimensions of performance are addressed, and to allow the scenarios to be accurately and consistently presented for repeated trials: • a description of the scenario and any pertinent prior history necessary for personnel to understand the state of the plant at the start-up of the scenario • specific initial conditions (a precise definition of the plant's functions, processes, systems, component conditions, and performance parameters, e.g., similar to that at shift turnover) • events (e.g., failures) that will occur during the scenario and their initiating conditions, e.g., based on time, or a value of a specific parameter • precise definition of workplace factors, (e.g., environmental conditions, such as low levels of illumination) • needs for task support (e.g., procedures and technical specifications) • staffing level • details of communication content between control room personnel and remote personnel (e.g., load dispatcher via telephone) • scripted responses for test personnel who will act as plant personnel in the test scenarios *Additional Information*: Test personnel act as surrogates for personnel outside the control room. To the greatest extent possible, prepare responses to questions that may be asked by operators communicating with the personnel outside the control room. There are limits to the ability to preplan communications because personnel may ask unanticipated questions or make unforeseen requests. However, efforts should be made to detail what information personnel outside the control room can provide, and script the responses to likely questions. • the precise specification of what, when, and how data are to be collected and stored (including videotaping, questionnaires, and rating-scale administrations) • precise specifications on simulator set up • specific criteria for terminating the scenario	Section 2.3, all

Review Criteria	HFE V&V IP Section No. and paragraph
(2) 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. (3) When the applicant's scenarios include work associated with operations remote from the main control room, the effects on personnel performance due to potentially harsh environments (e.g., high radiation) should be realistically simulated (e.g., additional time to don protective clothing, and access radiologically controlled areas).	Section 2.3, all
11.4.1.4 Additional Considerations for Reviewing the HFE Aspects of Plant Modifications In addition to any of the criteria above that relate to the modification being reviewed, the applicant should address the following considerations. (1) The applicant's operational conditions should reflect tasks that involve a modification, rather than the entire range of topics discussed in Section 11.4.1. (2) For ISV, the applicant's operational conditions should encompass the transfer of learning effects on personnel performance when modifying an old HSI or procedure. *Additional Information*: Negative transfer of learning may occur when the new and old components are different and impose different demands on personnel. (3) For ISV, when both old and new versions of the same HSIs are permanently present in the HSI but with different means of presentation and methods of operation, then the applicant's evaluations should reasonably assure that personnel can alternate their use of these HSIs without degrading performance. (4) Where old HSIs are to be deactivated but left in place in the HSI, the applicant should identify conditions for an ISV that would test the potential for their interfering with tasks. *Additional Information*: For example, the presence of deactivated HSIs may cause visual clutter that interferes with the ability of personnel to locate and use other HSIs.	N/A
11.4.2 Design Verification Review Criteria **(1) 11.4.2.1 HSI Inventory and Characterization** (1) Scope - 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. The inventory should include aspects of the HSI used for managing the interface, such as navigation and retrieving displays, as well as those that control the plant.	Section 3.1.1, all

Review Criteria	HFE V&V IP Section No. and paragraph

(2) HSI Characterization - The applicant's inventory should describe the characteristics of each HSI within the scope of the verification. The following is a minimal set of information for this characterization:
• a unique identification code number or name
• associated plant system and subsystem
• associated personnel functions and tasks
• type of HSI, e.g.,
  – computer-based control (e.g., touch screen or cursor-operated button and keyboard input)
  – hardwired control (e.g., J-handle controller, button, and automatic controller)
  – computer-based display (e.g., digital value and analog representation)
  – hardwired display (e.g., dial, gauge, and strip-chart recorder)
• display characteristics and functionality [e.g., plant variables/parameters, units of measure, accuracy of variable/parameter, precision of display, dynamic response, and display format (e.g., bar chart or trend plot)]
• control characteristics and functionality [e.g., continuous versus discrete settings, number and type of control modes, accuracy, precision, dynamic response, and control format (method of input)]
• user-system interaction and dialog types (e.g., navigation aids and menus)
• location in data-management system (e.g., identification code for information display screen)
• physical location in the HSI (e.g., control panel section), if applicable
 	
The applicant should include photographs, copies of display screens, or similar samples of HSIs in the HSI inventory and characterization.
	Section 3.1.2, all

(3) Inventory Verification - The applicant should verify the inventory description of HSIs to ensure that it accurately reflects their current state.	Section 3.1.3, all
11.4.2.2 HSI Task Support Verification HSI Task Support Verification addresses the availability of items needed to support task requirements. As stated in Section 11.2, the objective of the HSI Task Support Verification review is to ensure that the applicant verified that the HSI provides the needed alarms, information, controls, and task support for personnel to perform their tasks, defined by the task analysis. (1) Verification Criteria - 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 task analysis.	Section 3.2 Section 3.2.1, all
(2) General Methodology - 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 task analysis for the defined sampling of operational conditions, noted in Section 11.4.1.	Section 3.2.2, all
(3) HED Identification - The applicant should identify and document an HED when: • An HSI needed for task performance (e.g., a necessary control or	Section 5.1 all

Review Criteria	HFE V&V IP Section No. and paragraph
display) is unavailable. • HSI characteristics do not match the requirements of the personnel task (e.g., a display may show the needed plant parameter but not within the range or precision needed for the task). • HSIs are available that are not needed for any task. Additional Information: Unnecessary HSIs introduce clutter, and can distract personnel from selecting the appropriate ones. It is important to verify that the HSI is unnecessary. Appropriate ones may not appear to be needed with personnel tasks for the following reasons: • The HSI is essential for a task that the task analysis did not address (i.e., it was not within the scope of the design review). • The task analysis was incomplete, overlooking the need for the HSI. • The HSI only partially meets the established requirements for the personnel task.	
(4) HED Documentation – The applicant should document HEDs to identify the HSI, the tasks affected, and the basis for the deficiency (what aspect of the HSI was identified as not meeting task requirements). Additional Information: The analysis and correction of HEDs is detailed in Section 11.4.4, Human Engineering Discrepancy Resolution Review Criteria.	Section 5.2, all

Review Criteria	HFE V&V IP Section No. and paragraph
(5) Additional Methodology Considerations for Plant Modifications - In addition to any of the criteria above that relate to the modification being reviewed, the applicant should address the following considerations: • HSI Task Support Verification should address all aspects of HSIs described above related to the modification. For modifications to plant systems that do not include modifications of the HSIs, verification of task support should highlight any new demands for monitoring and control, and assess whether the existing HSI design adequately addresses them. • HSI Task Support Verification should cover configurations in the modification in which old HSIs are deactivated permanently, but not removed (e.g., abandoned in place). Criterion 4 in this subsection states that the HSIs should not contain any information, displays, or controls that do not support personnel tasks. This verification should identify deactivated HSIs that might negatively affect personnel performance, such as obstructing the view of important information or adding visual clutter that could interfere with monitoring. The applicant should identify deactivated HSIs requiring further evaluation through HFE design verification or ISV. • HSI Task Support Verification should address the temporary configurations of the HSIs and plant systems that may be created when establishing the modification, and so used by operations and maintenance personnel when the plant is not shutdown. These configurations may include: − the use of HSIs that differ from the intended final design − combinations of HSIs and system configurations that differ from both the original design and the intended final one For each temporary HSI configuration, the task requirements of personnel should be identified and compared to the information and control capabilities available. *Additional Information*: For example, if a temporary configuration of plant systems introduces special monitoring requirements, the HSIs should provide the necessary information.	N/A.

Review Criteria	HFE V&V IP Section No. and paragraph
11.4.2.3 HFE Design Verification HFE Design Verification addresses the suitability of the HSI with regard to human capabilities and limitations. As stated in Section 11.2, the objective of the HFE Design Verification review is to evaluate the applicant's verification that the design of the HSIs conforms to HFE guidelines. (1) Verification Criteria - The applicant should base the criteria used for HFE Design Verification on HFE guidelines. *Additional Information:* The choice of guidelines used in this verification depends upon whether the applicant developed a design-specific style guide. The acceptability of the style guide used by the applicant should be reviewed by the NRC staff using the review guidance in Section 8.4.3, HFE Design Guidance for HSIs. Using an NRC-reviewed style guide affords the criteria for verifying the HFE design. When no style guide is available, the guidelines in NUREG-0700 can be used by the applicant for this purpose. However, because not all of the guidelines therein will be applicable to each review, the applicant should select those based on the characteristics of the HSIs being evaluated. Applicants should identify a subset of guidelines appropriate to a specific design based on the HSI characterization.	Section 3.3 Section 3.3.1, all
(2) General Methodology - The applicant's HFE Design Verification methodology should include the following: • Procedures for comparing the characteristics of the HSIs with HFE guidelines for (1) the defined sampling of operational conditions, as noted in Section 11.4.1, and (2) the general environment in which HSIs are sited, including workstations, control rooms, and environmental characteristics (e.g., lighting and noise). *Additional Information:* A single guideline may apply to many HSIs. By verifying all HSIs within the scenarios defined in Section 11.4.1, the consistency of applying a guideline across multiple HSIs can be assessed. • Procedures for determining for each guideline whether the HSI is "acceptable" or "discrepant." If discrepant, it should be designated as an HED, tracked, and evaluated (see Sections 2.4.4 and 11.4.4). *Additional Information*: A judgment that an HSI is "acceptable" should be made only if compliance is total, i.e., only if every instance of the item is fully consistent with the criteria established by the HFE guidelines. If there is any noncompliance, full or partial, then an evaluation of "discrepant" should be given, and a notation made as to where it occurs. • Procedures for evaluating whether an HED is a potential indicator of additional issues. *Additional Information*: For example, identifying an inappropriate format for presenting data on an individual display should be considered a potential sign that other display formats might be used incorrectly, or that the observed format is employed inappropriately elsewhere. Then, the sampling strategy should be modified to encompass other display formats. In some cases, discovering these discrepancies will warrant further review in the identified areas of concern.	Section 3.3.2, all

Review Criteria	HFE V&V IP Section No. and paragraph
(3) HED Identification - The applicant should identify an HED when a characteristic of the HSI is "discrepant" from a guideline. (4) HED Documentation - The applicant should document HEDs in terms of the HSI involved, and how its characteristics depart from a particular guideline. *Additional Information*: The analysis and correction of HEDs is addressed in Section 11.4.4, Human Engineering Discrepancy Resolution Review Criteria.	Section 5.0
(5) Additional Considerations for Reviewing the HFE Aspects of Plant Modifications - In addition to any of the criteria above that relate to the modification being reviewed, the applicant should address the following considerations: • The scope of HFE design verification may be restricted to the modified HSIs and their interactions with the rest of the HSIs. • When both old and new versions of similar HSIs are available, this verification should offer reasonable assurance that their means of presentation and methods of operation are compatible, such that personnel performance will not be impaired when alternating the use of each one. • HEDs should be identified for the following: – failure to meet "personnel-identified" functionality in addition to that specified by system designers. When a digital system replaces an existing system, it is important to ensure that all operational uses of the former system were addressed, even those that were not intended in the original design. The replacement system's design should consider the ways in which personnel actually used the former system – poor integration with the rest of the HSI – poor integration with procedures and training • Temporary configurations of the HSIs and plant systems that operations and maintenance personnel may use when the plant is not shutdown, should be reviewed to verify that their design is consistent with the principles of good HFE design, including consistency with the rest of the HSIs.	N/A
11.4.3 Integrated System Validation **11.4.3.1 Validation Team** (1) The applicant should describe how the team performing the validation has independence from the personnel responsible for the actual design. *Additional Information*: The members of the Validation Team should have no responsibility for the design; i.e., they should never have been part of the design team. While they may work for the same organization, their responsibilities must not include contributions to the design, other than validating it.	Section 4.0 Section 4.1, all
11.4.3.2 Test Objectives (1) The applicant should develop detailed test objectives to provide evidence that the integrated system adequately supports plant personnel in safely operating the plant, to include the following considerations: • Validate the acceptability of the shift staffing level(s), the	Section 4.2, all

Review Criteria	HFE V&V IP Section No. and paragraph
assignment of tasks to crew members, and crew coordination within the control room, between the control room and local control stations and support centers, and with individuals performing tasks locally. This should encompass validating minimum shift staffing levels, nominal levels, maximum levels, and shift turnover (see Section 6 for definitions). • Validate that the design has adequate capability for alerting, informing controlling, and feedback such that personnel tasks are successfully completed during normal plant evolutions, transients, design-basis accidents, and also under selected, risk significant events beyond-design basis, as defined by sampling operational conditions. • Validate that specific personnel tasks can be accomplished within the time and performance criteria, with effective situational awareness, and acceptable workload levels that balance vigilance and personnel burden. • Validate that the HSIs minimize personnel error and assure error detection and recovery capability when errors occur. • Validate the assumptions about performance on important HAs. *Additional Information*: For example, the HRA within the plant PRA contains several assumptions regarding the performance of risk-important HAs. These assumptions should be validated for dominant sequences, such as decision-making and diagnosis strategies, and also for the human actions. This process should be completed before the final quantification stage of the PRA. • Validate that the personnel can effectively transition between the HSIs and procedures in accomplishing their tasks, and that interface management tasks, such as display configuration and navigation, are not a distraction or an undue burden.	
(2) Additional Considerations for Reviewing the HFE Aspects of Plant Modifications – In addition to any of the criteria above that relate to the modification being reviewed, the test's objectives and scenarios should be developed to encompass aspects of performance affected by the modified design (even when the HSIs are not modified), including personnel tasks.	N/A
11.4.3.3 Validation Test beds A test bed is the HSI representation used to perform validation evaluations. One approach an applicant can use to acceptably meet criteria 1 through 7 in this section is to use a test bed that is compliant with "Nuclear Power Plant Simulators for Use in Operator Training" (ANS, 2009). (1) Interface Completeness - The applicant's test bed should represent completely the integrated system. It should include HSIs and procedures not specifically required in the test scenarios. *Additional Information:* Adjacent controls and displays may affect the ways in which personnel use those addressed by a particular validation scenario.	Section 4.3 Section 4.3.1, all
(2) Interface Physical Fidelity - The test bed's HSIs and procedures should be represented with high physical fidelity to the reference design, including the presentation of alarms, displays, controls, job aids, procedures, communications equipment, interface management tools, layout, and spatial relationships.	Section 4.3.2, all
(3) Interface Functional Fidelity - The test bed's HSI and procedure	Section 4.3.3, all

Review Criteria	HFE V&V IP Section No. and paragraph
functionality should be represented with high fidelity to the reference design. All HSI functions should be available. *Additional Information:* High fidelity covers the HSI modes of operation (i.e., the changes in functionality that can be invoked by personnel selecting them), or changes in plant states.	
(4) Environmental Fidelity - The test bed's environmental fidelity should be represented with high physical fidelity to the reference design, including the expected levels of lighting, noise, temperature, and humidity. Thus, for example, the noise contributed by equipment, such as air-handling units, computers, and communications equipment should be represented in validation tests.	Section 4.3.4, all
(5) Data Completeness Fidelity - Information and data provided to personnel should completely represent the plant's systems they monitor and control.	Section 4.3.5, all
(6) Data Content Fidelity - The test bed's data content fidelity should be represented with high physical fidelity to the reference design. The presentation of information and controls should rest on an underlying model accurately mirroring the reference plant. The model should provide input to the HSI such that the information accurately matches that which is presented during operations.	Section 4.3.6, all
(7) Data Dynamics Fidelity - The test bed's data dynamics fidelity should be represented with high fidelity to the reference design. The process model should be able to provide input to the HSI so that information flow and control responses occur accurately and within the correct response time; e.g., information should be sent to personnel with the same delays as occur in the plant.	Section 4.3.7, all
(8) For important HAs at complex HSIs remote from the main control room (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. (For less important HAs, or for non-complex HSIs, human performance may be assessed on analysis, such as task analysis, rather than on simulations.)	Section 4.3.8, all
(9) The applicant should verify the conformance of the test bed to the test bed-required characteristics before validation tests are conducted.	Section 4.3.9, all
11.4.3.4 Plant Personnel (1) Participants in the applicant's validation tests should be representative of plant personnel who will interact with the HSI (e.g., licensed operators, rather than training personnel or engineers). (2) 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. Those characteristics expected to contribute to variations in system performance should be specifically identified; the sampling process should reasonably assure that the validation encompasses variation along that dimension. Determining representativeness should include considering the participants' license type and qualifications, skill/experience, age, and general demographics. (3) 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, reactor operators,	Section 4.4, all

Review Criteria	HFE V&V IP Section No. and paragraph
shift technical advisors, etc. (4) The applicant should prevent bias in the sample of participants by avoiding the use of participants who: • are members of the design organization • participated in prior evaluations • were selected for some specific characteristic, such as crews identified as good performers or more experienced	
11.4.3.5 Performance Measurement ISV employs a hierarchal set of performance measures including measures of plant performance, personnel task performance, situation awareness, cognitive workload, and anthropometric/physiological factors. Errors of omission and commission also are identified. A hierarchal set of measures provides sufficient information to validate the integrated system design and affords a basis to evaluate deficiencies in performance and thereby identify needed improvements. Pass/fail measures are those used to determine whether the design is or is not validated. Diagnostic measures are used to better understand personnel performance and to facilitate the analyses of errors and HEDs.	Section 4.5, all
11.4.3.5.1 Types of Performance Measures (1) The applicant should identify the specific plant performance measures applicable to each ISV scenario. • *Additional Information*: They may address the performance of functions, systems, or component.	Section 4.5.1.1, all

Review Criteria	**HFE V&V IP Section No. and paragraph**
(2) The applicant should identify the primary task measures applicable to each ISV scenario. • For each scenario, the applicant should identify the primary tasks operators must perform to accomplish scenario goals, so that such measures can be developed. *Additional Information*: The primary tasks are those involved in carrying out the functional role of the operator in supervising the plant; i.e., monitoring, detection, situation assessment, response planning, and response implementation. Primary tasks should be assessed at a level of detail appropriate to the task's demands. For example, for some simple scenarios, measuring the time to complete a task may suffice. For complicated tasks, especially those described as knowledge-based, it may be appropriate to undertake a fine-grained analysis, such as identifying the task's components, viz., seeking specific data, making decisions, taking actions, and obtaining feedback. • The measures chosen to evaluate personnel task performance should reflect those aspects of the task that are important to system performance, such as: – time – accuracy – frequency – amount achieved or accomplished – consumption or quantity used – subjective reports of participants – behavior categorization by observers • The analysis of primary tasks will support the identification of errors of omission (primary tasks not performed). Also, any actions and tasks that operators *actually* perform that deviate from the primary tasks should be identified and noted. These actions should be used to identify errors of commission.	Section 4.5.1.2, all
(3) The applicant should identify the secondary task measures applicable to each scenario. *Additional Information*: Secondary tasks are those personnel must perform when interfacing with the HSI, such as navigating through computer screens to find a needed display and to configure HSIs. The measurement of secondary task performance should reflect the demands of the detailed HSI implementation, e.g., time to configure a workstation, navigate between displays, and manipulate them (e.g., changing display type and scale settings).	Section 4.5.1.2, paragraph 3
(4) The applicant should identify the measures of situation awareness applicable to each scenario. *Additional Information*: Situation awareness is the degree to which personnel's perception of plant parameters and understanding of the plant's condition corresponds to its actual condition at any given time and influences predictions about future states.	Section 4.5.1.3, all
(5) The applicant should identify the workload measures obtained for each scenario. Additional Information: Workload is comprised of the physical, cognitive, and other demands that tasks place on plant personnel. The impact of one or many of these aspects of workload should be considered in the performance measures.	Section 4.5.1, all; Section 4.5.1.4

<table>
<tr><th>Review Criteria</th><th>HFE V&V IP Section No. and paragraph</th></tr>
<tr><td>(6) The applicant should identify the anthropometric and physiological measures obtained for each scenario.
Additional Information: Anthropometric and physiological factors include such concerns as visibility of displays, accessibility of control devices, and ease of manipulating the control device. Many of these design aspects are assessed as part of verifying the HFEs design. Therefore, attention should focus on those areas of the design that only can be addressed by testing the integrated system, e.g., the ability of personnel effectively to use the various controls, displays, workstations, or consoles while performing their tasks.</td><td>Section 4.5.1.5, all</td></tr>
<tr><td>11.4.3.5.2 Performance Measure Information and Validation Criteria
(1) The applicant should describe the methods by which these measures are obtained, e.g., by simulator data recording, participant questionnaires, or observation by subject-matter experts.</td><td>Section 4.5.2, all;
Section 4.5.2.1</td></tr>
<tr><td>(2) The applicant should specify when each measure is obtained (recorded), such as continuously, at specific points during the scenario, or after the scenario ends.</td><td>Section 4.5.2.2, paragraph 3</td></tr>
<tr><td>(3) The applicant should describe the characteristics (see Table 11-1) of the performance measures.

Table 11-1 Characteristics of Performance Measures
<table>
<tr><td>Characteristic</td><td>Meaning</td></tr>
<tr><td>Construct Validity</td><td>A measure should represent accurately the aspect of performance it is intended to measure.</td></tr>
<tr><td>Reliability</td><td>A measure should be repeatable; i.e., same behavior measured in exactly the same way under identical circumstances should yield the same results.</td></tr>
<tr><td>Sensitivity</td><td>A measure's range (scale) and its frequency (how often data are collected) should be appropriate to that aspect of performance being assessed.</td></tr>
<tr><td>Unobtrusiveness</td><td>A measure should minimally alter the psychological or physical processes that are being investigated.</td></tr>
<tr><td>Objectivity</td><td>A measure should be based on easily observed phenomena.</td></tr>
</table></td><td>Section 4.5.2.2, Table 4-1</td></tr>
<tr><td>(4) The applicant should identify the specific criterion for each measure used to judge the acceptability of performance and describe its basis.
Additional Information: Table 11-2 describes the different bases for performance criteria.
Table 11-2 Basis for Performance Criteria
<table>
<tr><td>Criteria</td><td>Basis Meaning</td></tr>
<tr><td>Requirement</td><td>The observed performance of the integrated system is compared with a quantified performance requirement; i.e., the requirements for the performance of systems, subsystems, and personnel are defined through engineering analyses.</td></tr>
</table></td><td>Section 4.5.2.2, Table 4-2</td></tr>
</table>

<table>
<tr><th>Review Criteria</th><th>HFE V&V IP Section No. and paragraph</th></tr>
<tr><td><table>
<tr><td>Benchmark</td><td>The observed performance of the integrated system is compared with a criterion established using a benchmark system, e.g., a current system is predefined as acceptable.</td></tr>
<tr><td>Norm</td><td>The observed performance of the integrated system is compared with a criterion using many predecessor systems (rather than a single benchmark system).</td></tr>
<tr><td>Expert Judgment</td><td>The observed performance of the integrated system is compared with a criterion established by subject-matter experts.</td></tr>
</table></td><td></td></tr>
<tr><td>(5) The applicant should identify whether each measure is a pass/fail one or a diagnostic one.</td><td>Section 4.5.2.2, final paragraph</td></tr>
<tr><td>11.4.3.6Test Design
11.4.3.6.1 Scenario Sequencing

(1) The applicant should balance scenarios across crews to provide each crew with a similar, representative range of scenarios. Additional Information: Random assignment of scenarios to crews for ISV is undesirable. The value of using random assignment to control bias is effective only when the number of crews is quite large.</td><td>Section 4.6
Section 4.6.1, all</td></tr>
<tr><td>(2) 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 (e.g., the easy scenario is not always used first).</td><td>Section 4.6.2, bullet 1</td></tr>
</table>

Review Criteria	HFE V&V IP Section No. and paragraph
11.4.3.6.2 Test Procedures (1) The applicant should use detailed, unambiguous procedures to govern the conduct of the tests. These procedures should include the following: • the identification of which crews receive which scenarios, and the order in which they should be presented • detailed and standardized instructions for briefing the participants *Additional Information:* The type of instructions given to participants can affect their performance on a task. This source of bias is minimized by developing standard instructions. • specific directions for the testing personnel on conducting the test scenarios, as elaborated in Scenario Definition (Section 11.4.1.3) • guidance on when and how to interact with participants when difficulties occur in simulation or testing *Additional Information:* Even when a high-fidelity simulator is used, the participants may encounter artifacts of the test environment that detract from their performance of the tasks that are the focus of the evaluation. Guidance should be available to the test conductors to help resolve such conditions. • instructions on when and how to collect and store data. These instructions should stipulate which data are to be recorded by: – simulator computers – special-purpose instruments and devices for collecting data (such as situation awareness- and workload-questionnaires, or physiological measures) – video recorders (locations and views) – test personnel and subject-matter experts (such as via observational checklists) • procedures for documentation: – identifying and maintaining files of test records including details of the crew and scenarios – data collected – logs created by those who conducted the tests • The procedures should detail the types of information that should be logged (e.g., when the tests were performed, deviations from the test procedures and why they occurred, and any unusual events that may be important to understanding how a test was run or for interpreting the findings from it). The procedure also should state when the types of information should be recorded.	Section 4.6.2, all

Review Criteria	HFE V&V IP Section No. and paragraph
(2) The applicant's test procedures should minimize the opportunity for bias in the test personnel's' expectations and in the participant's responses. *Additional Information*: The expectancies of test personnel may introduce a bias if the expectations of the testers systematically influence the collection of data. Expectancies can influence performance in many ways (e.g., test personnel may, by giving subtle cues or communications, provide direction to participants, or they may tend to evaluate the performance of participants in ways that reflect more favorably upon the design than would an objective observer). Participant response bias means that the design of the test itself affects the data obtained from participants. It is not necessarily implied that a response bias represents any deliberate attempt by the participants to be untruthful. The test environment can influence participants in ways that have little to do with the tests objectives. Response bias can occur in four ways. First, participants may wish to influence outcomes and so be biased toward producing data consistent with their desired result. Second, participants may want to provide data that they think the test personnel want to obtain. Third, participants may try to figure out how performance should vary under different conditions, and then influence data to be consistent with such differences. Fourth, participants may want to excel because they know that they are being observed. See NUREG/CR 6393 (O'Hara et al., 1997) for additional information.	Section 4.6.2, final paragraph
11.4.3.6.3 Training Test Personnel (1) The applicant should train test personnel (those who conduct or administer the validation tests) on the following: • the use and importance of test procedures • bias and errors that test personnel may introduce into the data through failures to follow test procedures accurately or to interact with participants properly • the importance of accurately documenting problems arising during testing, even if they were due to an oversight or error of those conducting the test	Section 4.6.3, all
11.4.3.6.4 Training Participants (1) The applicant's training of participants should be very similar to the training plant personnel receive. It should reasonably assure that the participants' knowledge of the plant's design, and operations, and the use of the HSIs and procedures represent that of experienced plant personnel. Participants should not be trained specifically to carry out the selected validation scenarios.	Section 4.6.4, paragraph 1
(2) 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 4.6.4, paragraph 2

Review Criteria	HFE V&V IP Section No. and paragraph
11.4.3.6.5 Pilot Testing (1) 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. (2) The applicant should not use participants in the pilot testing who will then be participants in the validation tests.	Section 4.6.5, all
11.4.3.7 Data Analysis and HED Identification (1) The applicant should use a combination of quantitative and qualitative methods to analyze data. The analysis should reveal the relationship between the observed performance and the established performance criteria.	Section 5.0
(2) 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 5.0
(3) The applicant should evaluate the degree of convergence between related measures (i.e., consistency between measures expected to assess the same aspect of performance). *Additional Information:* For example, if situation assessment is measured by both a participant questionnaire, and an observer rating scale, the results should be consistent with each other. If they do not converge, the reason for this should be identified.	Section 5.0
(4) 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 5.0
(5) The applicant should verify the correctness of the analyses of the data. This verification should be done by individuals or groups other than those who performed the original analysis, but may be from the same organization.	Section 5.0
(6) The applicant should identify HEDs when the observed performance does not meet the performance criteria. *Additional Information*: The analysis and correction of HEDs is addressed in Section 11.4.4, Human Engineering Discrepancy Resolution Review Criteria.	Section 5.0
(7) The applicant should resolve HEDs identified by pass/fail measures before the design is accepted.	Section 5.0

Review Criteria	**HFE V&V IP Section No. and paragraph**
11.4.3.8 Validation Conclusions (1) The applicant should document the statistical and logical bases for determining that performance of the integrated system is, and will be acceptable. (2) 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. *Additional Information:* Examples of possible limitations include: • aspects of the tests that were not well controlled • potential differences between the test situation and actual operations, such as the absence of productivity-safety conflicts • potential differences between the validated design and the as-built plant or system (if validation is directed to a plant under construction where such information is available, or to a new design using the validation findings from a predecessor)	Section 5.0

<table>
<tr><th>Review Criteria</th><th>HFE V&V IP Section No. and paragraph</th></tr>
<tr><td>11.4.4 Human Engineering Discrepancy Resolution Review Criteria

(1) HED Analysis
The applicant’s HED analyses should include the following:
Personnel Tasks and Functions – The impact of HEDs on personnel tasks and the functions supported by those tasks.
Additional Information: The potential effects of HEDs is determined, in part, by the importance of the personnel function to plant safety (e.g., consequences of failure), and their cumulative effect on personnel performance (e.g., degree of impairment and types of potential errors).
Plant Systems – The impact of HEDs on plant systems, considering the safety significance of that system(s), their effect on accident analyses, and their relationship to risk-significant sequences in the plant’s PRA.
Additional Information: The potential effects of these HEDs on the plant’s safety and personnel performance are determined, in part, by the safety significance of the plant system(s) related to the particular component.
Cumulative Effects of HEDs – The analysis of HEDs should identify the cumulative effects that multiple HEDs may have on plant safety and personnel performance.
Additional Information: Although an individual HED might not be considered sufficiently severe to warrant correction, the combined effect of several of them on a single aspect of the design could significantly degrade plant safety, and therefore, necessitate corrective action. Likewise, when a single plant system with multiple associated HEDs affects several HSIs, then their possible combined effect on the operation of that plant system should be considered.
HEDs as Indications of Broader Issues – As well as addressing specific HEDs, the applicant’s analysis should determine whether the HEDs point to potentially broader problems.
Additional Information: For example, identifying multiple HEDs associated with one particular aspect of the HSI design, such as the remote shutdown panel, also might suggest other problems with that aspect of the design, such as inconsistent use of design procedures and style guides. In some cases, findings from evaluating HEDs could warrant further review in the identified areas of concern, e.g., when multiple cases of mislabeling are found, the reviewers may wish to do a more complete examination of labeling.</td><td>Section 5.0</td></tr>
</table>

Review Criteria	**HFE V&V IP Section No. and paragraph**
(2) Selection of HEDs to Correct The applicant should conduct an evaluation to identify which HEDs to correct. The evaluation should identify those HEDs that are acceptable as is (The *Additional Information* below provides examples). The remaining discrepancies should be denoted as HEDs to be addressed by the HED-resolution process. HEDs the applicant should correct are those with direct safety consequences, namely, those that could adversely impact personnel performance such that the margin of plant safety may be reduced below an acceptable level. Unacceptability is indicated by such conditions as violations of Technical Specification safety limits, operating limits, or limiting conditions for operations, or failing an ISV pass/fail criterion. HEDs with potential safety impact, not as severe as those described above, also should be corrected unless the applicant justifies leaving the condition as is. The applicant should correct HEDs that may adversely impact personnel performance in a way that has potential consequences to plant performance or SSC operability, and personnel performance or efficiency. This may include failing to meet personnel information needs or violating HFE guidelines for tasks associated with plant productivity, availability, and protecting investment. *Additional Information:* HEDs could be acceptable within the context of the fully integrated design. The technical basis for such a determination could include an analysis of recent research literature, current practices, tradeoff studies, or design engineering evaluations.	Section 5.0, final paragraph
(3) Development of Design Solutions The applicant should identify design solutions to correct HEDs. As part of the design solution, the application should evaluate the interrelationships of individual HEDs. *Additional Information*: HEDs should not be considered in isolation and to the extent possible, their potential interactions should be considered when developing and implementing solutions. For example, if the HSI for a single plant system is associated with many HEDs, then the set of design solutions should be coordinated to enhance overall performance and avoid incompatibilities between individual solutions. Similarly, if a single plant system is associated with multiple HSIs associated with HEDs, then the design of individual solutions should be harmonized so that the outcome enhances rather than detracts from that system's operation. Approaches that develop design solutions to some HEDs before all are identified in a particular V&V activity are acceptable provided that the potential interactions between HEDs are specifically considered before implementing the design solutions.	Section 5.2, all Also described in Reference 8.2.1.

Review Criteria	HFE V&V IP Section No. and paragraph
(4) Design Solution Evaluation The applicant should evaluate design solutions to demonstrate the resolution of that HED and to ensure that new HEDs are not introduced. Generally, the evaluation should use the V&V method that originally detected the HED. *Additional Information*: For example, if the HED was identified using HFE Design Verification, then that verification should be employed to evaluate the solution. However, there may be reasons for documenting a satisfactory resolution using other methods. For example, if an aspect of the HSI was significantly changed from the resolution of multiple HEDs, the final HSI design may be validated to ensure that the net effect of all the changes is acceptable.	Section 5.2, all Also described in Reference 8.2.1.
(5) HED Evaluation Documentation The applicant should document each HED, including: • the basis for not correcting an HED • related personnel tasks and functions • related plant systems • cumulative effects of HEDs • HEDs as indications of broader issues *Additional Information*: Some, or all, of this documentation may be included in the issues tracking system (Section 2.4.4). Other information, such as cumulative effects or indications of broader issues, may be documented separately.	Section 5.2 all

8.0 References

8.1 Source Documents

8.1.1 U.S. Nuclear Regulatory Commission, “Human Factors Engineering Program Review Model,” NUREG-0711, Rev. 3, November 2012.

8.1.2 U.S. Nuclear Regulatory Commission, “Integrated System Validation: Methodology and Review Criteria,” NUREG/CR-6393, January 1997.

8.2 Referenced Documents

8.2.1 Human Factors Engineering Program Management Plan, RP-0914-8534.

8.2.2 NuScale Power Small Modular Reactor Human System Interface Style Guide, ES-0304-1381.

8.2.3 Human Factors Engineering Staffing and Qualifications Results Summary Report, RP-0316-17617.

Enclosure 5:

Human-System Interface Design Results Summary Report, RP-0316-17619-NP, Revision 0, non-proprietary version

Human Factors Engineering Human-System Interface Design Results Summary Report

12/02/2016

Revision 0

Docket: PROJ0769

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Abstract

This report documents the process NuScale Power, LLC (NuScale) followed to translate the functional and task requirements to the human-system interface (HSI) design requirements, and to the detailed design of alarms, displays, controls, and other aspects of the HSI. The results of this process produced a unique HSI Style Guide and a consistent state-of-the-art HSI design used by operators of the NuScale plant to carry out the plant's goals under normal, abnormal, and emergency operating conditions. This report also documents the methodology used to develop the HSI, the analysis performed on the HSI and the results of the analyses. The process used is consistent with the applicable provisions of Section 8 of U.S. Nuclear Regulatory Commission, "Human Factors Engineering Program Review Model," NUREG-0711, Rev. 3 (Reference 6.1.2).

Executive Summary

The NuScale HSI design was developed by a multi-faceted HFE design team that brought unique skills and knowledge to the effort and worked collaboratively and cohesively to reach the project goals. The NuScale HFE design team includes former nuclear plant operators and supervisors, plant system engineers, instrumentation & control (I&C) engineers, a simulator plant model, and HSI software developers and human factors engineers.

The plant functions, operator's tasks, and concepts of use were incorporated into the NuScale HSI Style Guide (Reference 6.2.2) for use by the HFE design team to produce a consistent state-of-the-art HSI design. The design team followed the NuScale HSI design and validation process to create and analyze the HSI that the operators will use to satisfy the plant's overall safety and operating objectives and goals.

The HSI was analyzed to verify in-scope tasks can be performed in a consistent and timely manner, verify the design took advantage of human and machine strengths to avoid human error and machine limitations, were consistent with the HSI Style Guide (Reference 6.2.2), and satisfied the guidance in Section 8 of NUREG-0711 (Reference 6.1.2). Staffing validation confirmed the main control room (MCR) layout and HSI design met the needs of the staffing and qualification effort discussed in the Human Factors Engineering Staffing and Qualifications Results Summary Report (Reference 6.2.7).

This report is organized as follows. Sections 1.0 and 2.0 provide an introduction to the HSI process and the HSI implementation process, respectively. Section 3.0 describes the methodology followed by the HFE design team during the development of the HSI. Section 4.0 provides a detailed summary of the results of the HSI effort including task support validation and design verification testing. Section 5.0 provides a high-level conclusion of the HSI effort. The source and referenced documents applicable to and used in the HSI effort are listed in Section 6.0. Examples of the HSI display pages are provided in Section 7.0. Finally, examples of the forms used during HSI testing process are provided in Appendix A through Appendix C.

This report supersedes RP-0914-8540, Human Factors Engineering Human-System Interface Design Implementation Plan, in its entirety.

1.0 Introduction

1.1 Purpose

The purpose of this results summary report (RSR) is to document the methodology and results of an iterative human-system interface (HSI) design process. This process translates the functional and task requirements to the HSI design requirements and to the detailed design of alarms, displays, controls, and other aspects of the HSI, which are based on systematically applying state-of-the-art human factors engineering (HFE) principles and the criteria to support the safe and reliable operation of the NuScale plant. Scope

This RSR includes a summary of the research, design, and testing efforts performed by the NuScale HFE design team that produced a coherent and consistent screen-based HSI design for the licensed operators located in the main control room (MCR) during normal, abnormal, and emergency operating conditions.

This RSR does not include results for ergonomic design, maintenance or refueling activities, environmental conditions, activities completed by craft/technical personnel (i.e., mechanical, electrical, or I&C, health physics, chemistry, engineering, or information technology), and activities associated with the remote shutdown station (RSS), the technical support center (TSC), emergency operations facility (EOF), operations support center, or any other emergency response facilities unless they were determined to impact licensed operator workload.

The NuScale HSI design and validation process addresses:

- the guidance documents used for the HSI detailed design.
- the in-scope facilities and HSIs within those facilities covering form, function, and performance characteristics.
- required inputs to the HSI design process.
- the concept of how HSIs are used and an overview of the HSI design process.
- alarms, cautions, status indications, controls, and computer-based procedures.
- systems used to communicate with personnel outside the MCR.
- how the design minimizes the effects of degraded I&C and HSI conditions on the performance of personnel.
- the outcomes of tests and evaluations undertaken to support the HSI design.

This RSR also documents the efforts performed by the HFE design team that produced an HSI that:

- supports the crew's tasks under normal, abnormal, and emergency operating conditions.
- accounts for the strengths and limitations of human operators.
- incorporates state-of-the-art HFE/HSI principles, technology, and overall design features.
- supports the MCR staffing plan validation (SPV) for the safe control and monitoring of 12 NuScale Power Modules and the common systems associated with them.

1.2 Abbreviations and Definitions

Table 1-1. Abbreviations

Term	Definition
BISI	bypassed and inoperable status indication
BOP	balance of plant
CCF	common cause failure
CIS	containment isolation signal
CIO	containment isolation override
CRS	control room supervisor
CVC	chemical & volume control
DAS	data acquisition system
DCA	design certification application
DHR	decay heat removal
DMI	demin isolation signal
ECC	emergency core cooling
EOF	emergency operations facility
FRA/FA	functional requirements analysis and function allocation
GVD	group view display
HED	human engineering discrepancy
HFE	human factors engineering
HFEITS	human factors engineering issue tracking system
HRA	human reliability analysis
HSI	human-system interface
I&C	instrumentation & control
IHA	important human action
IRM	information and records management
ISV	integrated system validation
LCS	local control station

Term	Definition
MCR	main control room
MCS	module control system
MPS	module protection system
NSE	Non-safety enable
NSIDE	NuScale simulator interface development environment
OER	operating experience review
P&ID	piping and instrumentation diagram
PAM	post-accident monitoring
PCS	plant control system
PHT	pressurizer heater manual actuation
PPS	plant protection system
PRA	probabilistic risk assessment
PWR	pressurized water reactor
RO	reactor operator
RSR	results summary report
RSS	remote shutdown station
RTS	reactor trip signal
RXM	reactor module
S&Q	staffing and qualification
SA	situational awareness
SDCV	spatially dedicated continuously visible
SDI	safety display and indication
SM	shift manager
SMR	small modular reactor
SOC	sampling of operational conditions
SPV	staffing plan validation
SSC	structure, system and component
STA	shift technical advisor
TA	task analysis
TSC	technical support center
V&V	verification & validation
VDU	visual display units
WLA	work load analysis
WPF	windows presentation foundation

Table 1-2. Definitions

Term	Definition
Computer-Based Procedure	A computer-based procedure system assists plant personnel by computerizing paper-based procedures. Their purpose is to guide operators' actions in performing their tasks in order to increase the likelihood that the goals of the tasks will be safely achieved.

Term	Definition
DOORS	Dynamic Object Oriented Requirements software is designed to capture, trace, analyze, and manage requirements while maintaining compliance with industry standards and regulations.
Embedded Procedure	{{ }}2(a),(c)
HFE Design Team	Generic term for the Plant Operations organization which consists of Operators, Human Factor Engineers, and Simulator Developers. The HFE Design Team does not include Plant Personnel. The HFE Design Team is responsible for the human factors engineering associated with the NuScale design. Also referred to as the design team.
Human System Interface	The human-system interface (HSI) is that part of the system through which personnel interact to perform their functions and tasks. In this document, "system" refers to a nuclear power plant. Major HSIs include alarms, information displays, controls, and procedures. Use of HSIs can be influenced directly by factors such as, (1) the organization of HSIs into workstations (e.g., consoles and panels) (2) the arrangement of workstations and supporting equipment into facilities such as a main control room, remote shutdown station, local control station, technical support center, and emergency operations facility and (3) the environmental conditions in which the HSIs are used, including temperature, humidity, ventilation, illumination, and noise. HSI use can also be affected indirectly by other aspects of plant design and operation such as crew training, shift schedules, work practices, and management and organizational factors.
{{ }}2(a),(c)	{{ }}2(a),(c)
Process Library	{{ }}2(a),(c)
Screen-based HSI	A defined set of information that is intended to be displayed as a single unit. Typical nuclear power plant display pages may combine several different formats on a single display screen, such as putting bar charts and digital displays in a graphic P&ID format. Display pages typically have a label and designation within the computer system so they can be assessed by operators as a single "display."
Video Display Unit	An electronic device for the display of visual information in the form of text and/or graphics.
VISION	The VISION® Developer application is a relational database that is used to store the FRA/FA, task analysis, staffing and qualifications analysis, development of human-system interfaces (HSI), procedures, and training data. In this document it may be referred to as the "FRA/FA & TA database" or "database".

2.0 Implementation

2.1 Human-System Interface Design Process Overview

The analyses performed in the early stages of the HFE program are important steps in establishing the inputs to the design requirements for the NuScale HSIs. The HSI design inputs that are analyzed and/or developed include the following:

- operating experience review (OER)
- functional requirements analysis and function allocation (FRA/FA)
- task analysis (TA)
- staffing and qualifications (S&Q)
- treatment of important human actions (IHAs)
- concept of operations
- I&C systems design
- alarm management
- system requirements
- HSI Style Guide

Once the inputs are established, the design effort follows the NuScale HSI process steps listed below when designing the MCR, conceptual workstations, and screen-based HSIs needed to complete the design effort.

1. Follow the appropriate chapters of the NuScale HSI Style Guide needed to establish a safe, user-friendly work location.
2. Follow the appropriate chapters of the NuScale HSI Style Guide needed to establish safe, user-friendly workstations.
3. Design and develop the HSI needed to accomplish safe and reliable operation of the plant.
4. Test and evaluate the HFE/HSI design of the simulator and products developed to support SPV testing

The HSI design products are the physical HSI screens, the embedded procedure functionality, and the plant notification functionality maintained within the simulator control room hardware and software. Examples and illustrations of these results are provided in Section 4.0 of this report.

2.2 Human-System Interface Design Team Composition and Responsibilities

2.2.1 Human-System Interface Design Team Composition

The NuScale HFE/HSI design process is instituted by a multi-faceted HFE design team that brings unique skills and knowledge to the effort and works collaboratively and cohesively to reach the projects goals. The HFE design team includes former nuclear plant operators and supervisors, plant system engineers, instrumentation and controls engineers, human factors engineers and software developers that work collaboratively and cohesively to reach the projects goals. This unique membership combination provides representation from all user and designer perspectives.

2.2.2 Simulator Development Responsibility

The HFE design team begins by designing an MCR simulator. An MCR simulator, referred to as simulator for the remainder of this document, is a computer-based, interactive work location that brings the operators as close as practicable to a true representation of the NuScale plant responses and user interfaces located in the MCR. The simulator is where the design team carries out rapid development, tests evolving state-of-the-art HSI design, and validates the NuScale MCR concepts and staffing goals. The simulator is also an effective tool for demonstrating plant operating and control concepts.

2.2.3 Human-System Interface Development Responsibility

The NuScale HSI design incorporates results of the OER, literature reviews, informal trade-off evaluations, informal consideration of multiple alternatives, and tests and evaluations. These support the technical basis for demonstrating that the design is state-of-the-art and supports personnel performance.

2.2.4 General Considerations

The following design goals are emphasized during the HSI design and evaluation process:

- {{

}}2(a),(c)

- {{

}}2(a),(c)

2.2.5 Special Considerations for the Human-System Interface Design

The following special high-level design considerations identified as part of a preliminary analysis of the essential and desirable features of an HSI for the NuScale plant are emphasized during the HSI design and evaluation process:

- {{

}}2(a),(c)

3.0 Methodology

3.1 Human-System Interface Design Inputs

3.1.1 Personnel Task Requirements

The analyses discussed below are performed in the early stages of an HFE program and are used to establish design requirements for the NuScale HSIs.

During operating experience review (Reference 6.2.4), issues from other plants and similar HSI designs are evaluated for inclusion or exclusion in the NuScale HSI design. The HSI design element confirms that the issues found during OER remain adequately addressed as the HSI design progresses. Discovered OER issues are resolved within the HSI design element or tracked in the human factors engineering issues tracking system (HFEITS) as applicable.

During functional requirements analysis and function allocation (Reference 6.2.5), the NuScale plant system functions that support safety are defined. Each system function is analyzed to determine the tasks, how the task is performed (manual, automated, or both), the technical basis, and the role of the operator. Safety functions are used as input to the design of the overview screens within the HSI inventory. HSIs for lower level functions are further analyzed during task analysis. Automation criteria established during function allocation define the levels of automation anticipated for the HSI design. HSI design issues initiated in FRA/FA are also generally resolved during HSI design.

The task analysis (Reference 6.2.6) provides the information needed to build a complete HSI inventory and the characteristics of that inventory needed to monitor and control critical functions during normal and abnormal operating conditions. Alarms, indications, procedures, and backup control for automated functions are also defined during TA. While building the HSI inventory during TA, characteristics such as alarm conditions, indication range and resolution, control function modes and accuracy, and procedure applicability conditions are established. Grouping of HSI elements in TA leads to HSIs designed for specific tasks and may reduce both reliance on system-based HSIs and navigation between screens. Task support requirements are defined in TA and may be implemented during HSI design or as issues tracked for resolution by other engineering disciplines.

HSI design considers IHAs from the probabilistic risk analysis (PRA) and from deterministic analyses (see Reference 6.2.9) to determine if the assumptions regarding HSI characteristics for IHAs are implemented in the HSI; for example,

- reduction of time required for human actions via simplified or reduced navigation.
- development of dedicated HSI.

- developing alarms specifically associated with IHAs.

The MCR layout considers providing workstations and video display units (VDUs) needed for the monitoring and control of multiple units and the common systems associated with them. Staffing and qualification analyses (Reference 6.2.9) are used to provide input to the HSI design by influencing the HSI hierarchy and navigation concepts, allocation of controls and displays to individual VDUs, and overall MCR layout. The S&Q analyses also validate the MCR crew complement and responsibilities of each member of the crew.

3.2 Simulator Development

The development of the simulator is at the center of three major NuScale work efforts. The various aspects of the simulator design processes are interlinked as shown in Figure 3-1.

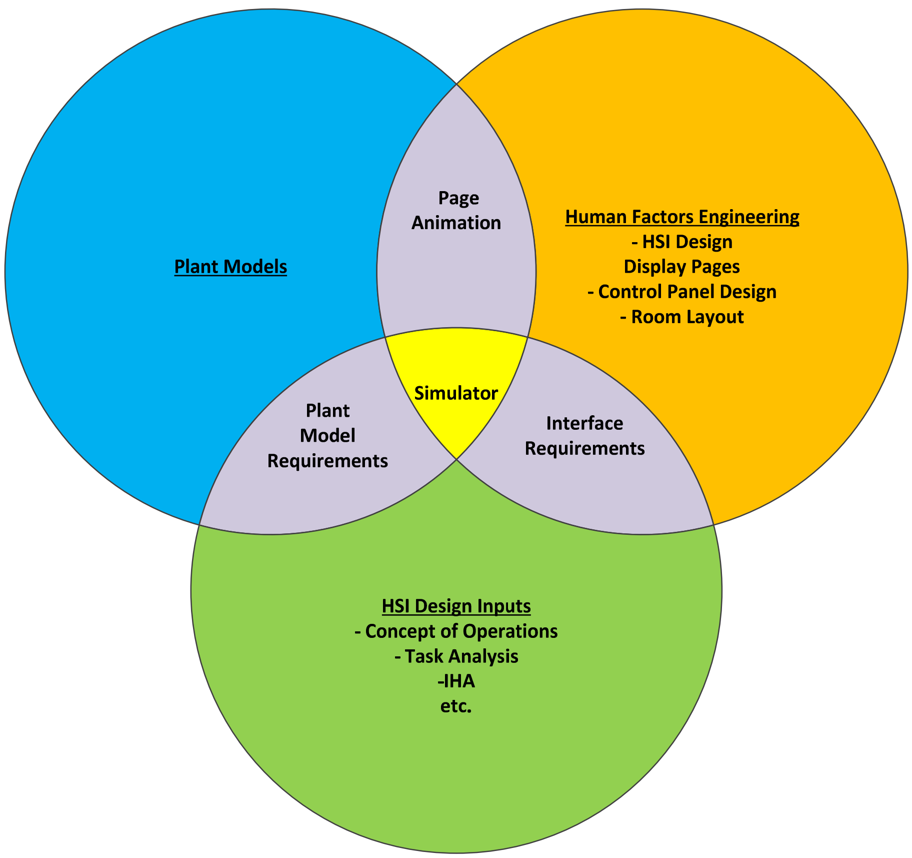

Figure 3-1. NuScale main control room simulator development Venn diagram

All of the elements shown are needed to design the simulator and are defined below:

- HSI design input – Discussed in Section 3.1
- Plant model requirements – functionality needed from the plant models to support the HSI and simulator design efforts. The appropriate HSI design inputs are used to help determine the needs.
- Plant models – set of models used to closely model and predicted behavior of the NuScale design.
- Page animation – HSI software that provides the operators an interface to the plant models.
- Human factors engineering – design effort discussed in this RSR
- Interface requirements –includes the NuScale HSI Style Guide as well as any of the input's information that drives HSI display page information (e.g. FRA/FA and TA).
- Simulator – needed to support the necessary modeling to complete staffing plan validation.

The HSI process discussed in this RSR is highlighted in orange in Figure 3-1. The other elements shown are discussed at a high level and are needed to develop the simulator and accomplish the goals discussed in Section 8 of Reference 6.1.2.

In more traditional simulator strategies, a simulator is developed for training and qualifying plant operators. The NuScale simulator is an evolutionary expression of the MCR interface that is built incrementally and represents the design detail as it emerges.

The HFE design team ensures that the partnerships between various NuScale plant design communities and the use of the appropriate guidance documents drive the simulator and HSI design to support:

- minimizing the probability that errors will occur.
- maximizing the probability that any error made is detected.
- analyses of personnel roles (job analysis).
- systematic strategies for organization, such as arrangement by importance, and frequency and sequence of use.
- the inspection, maintenance, test, and repair of (1) plant equipment, and (2) the HSIs.
- personnel task performance under all staffing conditions (minimum, typical, and high-level or maximum).
- consistent design for the HSIs.

- philosophy for updating the HSIs.
- procedures.
- automation.

3.3 Human-System Interface Design Overview

An iterative methodology incorporating the HSI design inputs (Section 3.1), analysis of personnel task requirements, system and regulatory requirements, concept of use, and general requirements, is used to develop the HSI conceptual design. The iterative design and evaluation approach serves to

- guide the selection of one from multiple candidate designs.
- answer open HFE questions related to situational awareness (SA), workload, and staffing.
- identify and eliminate HFE issues from the design early in the process.

Feedback from users on HSI prototypes is incorporated prior to the detailed design effort.

The iterative design of the HSI is closely connected with other HFE activities. As a part of each design effort, the HFE team presents findings and solicits input from the following design disciplines:

- I&C and computer systems – consider whether the design concepts are technically feasible, with a special emphasis on performance requirements
- human reliability analysis (HRA) process – consider plant conditions, risk-important human actions and HSIs identified as being important to plant safety and reliability or operator actions credited for achieving plant stabilization when automatic actions are not triggered
- S&Q plan efforts – determine any deficiencies or features of the design that are incompatible with the proposed staffing model
- procedure development – HSI design supports clear, reasonable procedures and vice versa
- training program development – consider the feasibility of the operator skills, rules, and knowledge necessitated by the proposed design

3.3.1 Survey of State-of-the-Art in HSI Technologies

The state-of-the-art HSI technology is established with an emphasis on adaptability, principles, and design patterns that serve the needs of the NuScale plant. Various options are evaluated for human usability and technical feasibility. Specific software and hardware development is not in the scope of the survey; however, an understanding of the state-of-the-art software and hardware technologies provides insight for development of the functional and procurement specifications for the HSI platform.

3.3.2 Preparation of Human-System Interface Design Support Documentation

Due to the iterative nature of the NuScale design, the following documents have the potential to be updated during HSI conceptual design:

- Concept of Operations
- HSI Style Guide

Note that these documents are revised as necessary throughout the design process as findings from testing and analyses are developed.

3.3.3 Conceptual Sketches

Conceptual screen sketches are aimed at creating a template page of a system or process that conforms to a subset of the HSI functional requirements. A template page is developed for each major portion of the HSI (e.g., task-based screens, computer-based procedures interfaces, overview displays). The level of detail of the template coincides with the maturity of the plant design for that type of interface. Representative screens and task sequences are selected for depiction, demonstrating key concepts, features and interactions, and for providing concrete grounds for analysis and feedback. Conceptual sketches incorporate the best understanding of design principles as outlined in the latest HSI Style Guide.

Conceptual sketches are maintained as design records.

Screen designers produce multiple candidate approaches for the conceptual sketches. Major components that are initially investigated in this manner include:

- template for screen layout(s)
- navigation schema
- information visualization approaches
- advanced alarm system interface
- computer-based procedures integration

If elements of the conceptual sketches, once reviewed, bring positive features to the overall design, changes to the HSI Style Guide are made accordingly.

3.3.4 Rapid Prototyping

Based on the latest conceptual sketches and feedback from interfacing with other disciplines, mock-ups or prototype screens integrated with a software simulator of the system are developed for review and evaluation. While the prototype provides a realistic user experience with the system, the focus is on testing design concepts and soliciting feedback, rather than producing an engineering-quality software architecture and user interface.

3.3.5 Tests and Evaluations

HSI design tests and evaluations are conducted and include trade-off evaluations and performance-based tests.

Trade-off evaluations pertain to comparing HSI design approaches and consideration of alternatives. In comparing HSI design approaches, consideration is given to ways to enhance human performance for performance of tasks, including IHAs.

Performance-based tests are performed to validate that the integrated system design (i.e., hardware, software, procedures, and personnel elements) supports the safe operation of the plant. The staffing plan validation is a performance-based test that is discussed in Section 4.8.4.

3.4 Human-System Interface Concept of Use

3.4.1 Operator Roles and Responsibilities

MCR licensed operators and operating crews outside the MCR are responsible for safe operation of the common plant, each individual unit and for maintaining power production. To achieve these objectives, the operators perform a variety of activities such as:

- structure, system and component (SSC) performance monitoring
- local and remote SSC operation
- commanding automated sequences
- directing subordinate operators to perform procedures
- monitoring the performance of sequences and procedures
- interrupting and reprioritizing sequences or procedures
- summoning additional resources to expand capabilities
- monitoring and evaluating technical specification conditions
- surveillance testing

- reviewing trends
- responding to off-normal conditions
- responding to alerts and alarms
- establishing plant conditions to support preventative or corrective maintenance, testing, and inspections
- maneuvering the plant
- performing emergency response duties such as offsite notifications
- performing non-emergency off-site reporting
- maintain a narrative log of events and activities that are relevant to the plant site
- communicating plant status, constraints, and planned actions to the appropriate stakeholders

Operators are guided in the performance of these activities by regulations, procedures, guidelines, training, and experience.

Operators follow procedures for equipment operation. Procedures direct the operation of components in the field, remote operation of components from the MCR, and the monitoring of automation to perform sub-steps, steps, and sequences to support the systems operation. Designing an integrated system for operation and monitoring roles at any location is a goal of the HFE design team.

3.4.2 Automation Roles

Automation plays a key role in the control of a NuScale plant. Beyond controlling plant functions and systems, automation is applied to a wide range of other functions, including monitoring and notification, situational assessment, response planning, response implementation, and interface management. Automation is a critical component of the HSI design and supports operators in operation of the plant. Examples of automation as a function of the HSI design are:

- placing equipment in service, conducting tests, and controlling processes
- automated notifications and recommended sequences
- performance of sequences not suited to manual operation (see description of process control roles below)

3.4.2.1 Process Control Roles

The control system continuously monitors key plant parameters. When one of these parameters approaches a control limit, the process control responds automatically to adjust the process. Depending on the parameter, the associated automation (process control) may respond with or without operator consent depending on the task. The criteria used to develop the process control systems roles are discussed below:

- continuous monitoring – the NuScale plant relies on automation to control basic intermittent and continuous processes (such as hot well level control or turbine speed control) and provide continuous process parameter monitoring
- repetitive tasks – those that involve multiple identical component manipulations, error-likely tasks for operators
- high cognizant burden functions – such as plant maneuvering, control rod exercising and valve testing, pressurizer level and coolant temperature control
- startup and shutdown support
- power maneuvering evolution support
- plant notifications – monitoring of plant parameters to provide visual and audible cues to the operator to maintain situational awareness and support the need to take manual control
- data historian – monitors parameters and evolutions to safely operate and report on the condition of the plant
- {{

  }}2(a),(c)

3.4.3 Shared Roles

The HFE design team uses the following set of criteria to provide the information necessary to coordinate the shared activity when developing the HSI.

3.4.3.1 Parameter Monitoring

Automation performs functions associated with parameter and process monitoring, defined sequence functions, continuous process control, alert and alarm monitoring, safety limit monitoring, and automatic safety functions including monitoring. Operators monitor and evaluate automated functions intervening as required.

Properly providing the operators with the ability to monitor process parameters being controlled by automation supports situational awareness and enables the operator to evaluate automated system performance and intervene, as necessary. Operators increase attention to system performance monitoring when:

- transients are anticipated
- sustained normal automated operation needs to be confirmed
- degraded automation is suspected

3.4.3.2 Operator Intervention

Operators intervene when the automation is asking for consent or when it becomes apparent that the automation has failed or is no longer appropriate for the current or planned plant conditions. The criterion for operator intervention involves judgment of continued safe operation of the plant.

3.4.4 Document Review

When appropriate, operators access an information and records management (IRM) system to review technical documents, reports, test results, and other work documents to confirm the readiness of SSCs.

3.4.5 Main Control Room Layout

The list below outlines the MCR layout design concepts used to develop the HSI features discussed in this document. Original design concepts were based on OER from operating nuclear power plants and control rooms from various industries in which few operators operate multiple units.

The NuScale MCR concept includes the following attributes:

- a bank of VDUs configured with spatially dedicated continuously visible (SDCV) HSIs (e.g., post-accident monitoring (PAM) variables, “manual” backups for protective functions)
- sit-down workstations for three reactor operators, each able to access HSIs for all units
- sit-down workstations for three senior reactor operators (shift manager (SM), shift technical advisor (STA), control room supervisor (CRS), each able to access HSIs for all units
- a dedicated unit stand-up workstation for each unit to allow focused operation of that unit
- a dedicated workstation for shared or common systems

- technologies to support teamwork and communications including individual and group plant notification techniques and non-wireless communication such as standard phone, verbal and e-mail protocols

3.5 Human Factors Engineering/Human-System Interface Design Guidance

3.5.1 HSI Style Guide

The NuScale HSI Style Guide applies to pertinent HSIs throughout the plant. The style guide includes a description of applicability for the included guidance. HSI designers consider the environment in which the HSIs are to be used, for example, colors, brightness and contrast, ambient lighting, and element spacing. Parameters such as accessibility, lighting, air quality, sound levels and quality, heat and humidity, and radiation zones are also considered in the design of HSIs.

The NuScale HSI design employs an inclusive HSI Style Guide for various types and formats of HSIs. The design criteria listed below illustrates how the style guide is used during HSI design.

The topics in the style guide address the scope of HSIs included in the design, and address their form, function, and operation, as well as the environmental conditions in which they will be used that are relevant to human performance. The style guide is consistent with the guidance of NUREG-0700 (Reference 6.1.1)

HFE guidance and HSI design-related analyses are used to develop the guidance in the style guide. The style guide influences the design decisions that address specific goals of the HSI design .Specific analyses related to HSI design include an evaluation of recent literature, analysis of current industry practices and operational experience, tradeoff studies, and the findings from design-engineering experiments and evaluations.

The style guide expresses precisely and describes easily observable HSI characteristics, such as “Alarms are shown in red.” The style guide contains sufficient detail so that design personnel can deliver a consistent, verifiable design.

The style guide contains instructions for determining where and how HFE guidance is used in the overall design process. The instructions are written so designers can readily understand them; the text is supplemented with graphical examples, figures, and tables to facilitate comprehension.

The style guide is maintained in a form that is readily accessible and usable by designers, and is easily modified and updated as needed. Each guidance statement includes a reference(s) to the source upon which it is based.

3.5.2 Concept of Operations

The concept of operations provides an overview of the supporting processes, individual roles, overall staffing, organizational values, crew structure, and operating techniques used by the crews of a NuScale plant to achieve a high level of safety and production.

The concept of operations is refined as the design, engineering and simulator evaluation associated with safety analysis, system design, control system automation, and human-system interface progresses.

3.5.3 Conduct of Operations

The conduct of operations provides a set of standards to influence operator behaviors to ensure high quality, consistent task performance that supports the safe and reliable operation of the NuScale plant. The conduct of operations is applicable to on-shift operations staff.

The conduct of operations is refined as the design, engineering and simulator evaluation associated with safety analysis, system design, control system automation, and human-system interface progresses.

3.6 Human-System Interface Detailed Design and Integration

In addition to the input elements discussed in Section 3.1 the HFE design team also takes into consideration the design elements listed below during the HSI design process. The team addresses each area individually and applies the results to the overall HSI design.

- important human actions
- HSI layout bases
- HSI support for inspection, maintenance, and testing
- support for staffing conditions
- human performance and fatigue
- environmental conditions
- HSI updates of plant modifications

3.7 Human-System Interface Tests and Evaluation Overview

This section describes the method NuScale uses to verify and document the review of the HSI displays, controls, and related equipment lying within the scope defined by the sampling of operational conditions (SOC) discussed in the Control Room Staffing Plan Validation Methodology, RP-1215-20253 (Reference 6.2.10).

Detailed design is a stage of development for a certain portion of the HSI. Different portions of the overall HSI are in conceptual design or detailed design depending on their level of development. Detailed design applies to the information gained from the iterative conceptual design phases to the production of a comprehensive HSI design.

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3.7.1 Internal Review of Design

Before performing tests on a hardware or software implementation, the design is subject to review. The review identifies HFE issues to be addressed prior to experimental evaluation and ensures that the design maturity is commensurate with the current design phase. Review of the design may also generate HFE questions or identify design trade-offs that cannot be resolved via static analysis, and should be considered for inclusion in subsequent tests.

The review steps include {{

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3.7.2 Testing and Evaluation of Design

Testing and evaluation consists of several stages.

Table 3-1 shows anticipated testing and evaluation efforts with respect to design phase.

Table 3-1. Iterative human-system interface design and evaluation plan

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The following criteria are used to select the design approach. Once a design approach is advanced enough to be tested, these criteria are used to determine whether or not a design approach will be part of detailed design.

- Are all personnel-task requirements considered?
- Does the design approach take advantage of human-performance capabilities and limitations?
- Does the design approach enhance HSI-system performance requirements?
- Does the design approach unduly increase inspection and testing needs or maintenance demands?
- Is proven technology used in the design approach?
- Has the design approach taken into account the operating experience review findings?

3.7.3 Iteration Decision Point

The HFE team conducts a design review following completion of the testing and compilation of the results to determine the next steps. The HSI design tested may be accepted as is, re-designed, or tabled pending further development or testing.

3.7.4 Human Engineering Discrepancy Resolution

Human engineering discrepancies (HEDs) are identified throughout the HSI design process to ensure that HEDs are being discovered, documented, and resolved accordingly. NuScale begins to record HEDs after the completion of staffing plan validation. At this point in the HSI design process, the HFE team can use the HSI used for Staffing Plan Validation as a baseline to work from for recording HEDs.

HEDs may not always be resolved; HEDs may be found acceptable after an evaluation in the context of the integrated design. The basis for a decision for accepting an HED without change in the integrated design is documented. It may be based on accepted HFE practices, currently published HFE literature, trade-off studies, tests, or engineering evaluations.

4.0 Results

4.1 Human-System Interface Design Inputs

NuScale utilized the collective operating experience of its design staff, FRA/FA and TA results, tabletop activities and preliminary simulator observations to determine initial staffing levels. The initial staffing level and qualifications for the NuScale control room operators as defined in the concept of operations (Reference 6.2.1) provided the basis for the development of the control room, workstation, and group view display (GVD) layout, which led to the construction of the MCR simulator. The control room communications protocols used by the control room operators are defined in the conduct of operations.

All of the above inputs in conjunction with the NuScale passive safety systems, simple operation, automation, expected reduced licensed operator workload, and limited number of IHAs led to the first of a kind, state-of-the art HSI design that successfully met the needs of and enhanced the ability of six licensed operators to safely and reliably operate a 12-unit power plant.

4.1.1 Personnel Task Requirements

4.1.1.1 Documented Results of Human-System Interface Inputs

The following documents discuss the results of the specific HSI input effort.

1. The Human Factors Engineering Operating Experience Review Results Summary Report (Reference 6.2.4).
2. The Human Factors Engineering Functional Requirements Analysis and Function Allocation Results Summary Report (Reference 6.2.5).
3. The Human Factors Engineering Task Analysis Result Summary Report (Reference 6.2.6).
4. The Human Factors Engineering Staffing and Qualifications Results Summary Report (Reference 6.2.7).

4.1.1.2 Key Influences

Listed below are some of the key influences to the HSI design provided by the input efforts:

1. NuScale performed a site visit where it was noted that over 500 alarms for the HVAC system alone were alarming. Alarm notifications were determined by design engineering without operations and HFE input. This visit drove the NuScale HFE team to design more effective notification criteria.

2. NuScale utilized the expertise of its HFE team members to perform reviews of NuScale design documents and provide recommendations for improvements and refinements to the design as appropriate. These personnel possessed significant experience in the operation of commercial nuclear power plants, and were an integral part of the HFE team. The safety functions and the information provided from these reviews were used by the HSFE design team as inputs to the design of the Unit Overview, Plant Overview and Safety Function Monitoring pages (Section 7.0).
3. System automation criteria (levels of automation anticipated for the HSI design) established during function allocation development directly drove the development of the Process Library page shown in Section 7.0.
4. The detailed information, control requirements (e.g., requirements for display range, precision, accuracy, and units of measurement) and tasks needed to control the plant during a range of operating conditions from normal through accident conditions helped create:
   - individual system pages.
   - overall navigation schema.
   - notification schema.
   - group view display pages.
   - embedded procedures.
   - automation interface.
5. Hardware toggle switches were located at the stand-up unit workstations to satisfy Regulatory Guide 1.62 requirements.

4.1.2 Applicable Regulatory Guidance for Human-System Interface Development

4.1.2.1 System Requirements

There are no known I&C platform system constraints related to the MCR layout optimization or HSI design for monitoring and control of multiple units.

4.1.2.2 Regulatory Requirements/Guidance

The code of federal regulations, staff requirements memoranda, Nuclear Regulatory Commission Regulation (NUREG's), and regulatory guides considered during the HSI design process are listed in the applicable elements of Reference 6.1.2.

4.1.2.3 Other Requirements

Other requirements used in the HSI design are described with respect to specific design features as applicable.

4.2 Main Control Room Simulator

Simulator readiness to support staffing validation was essential for testing in a meaningful way. The simulator allowed the operators to interface with working models of the plant design and allowed concepts of operation to be put into practice. The NuScale simulator uses high fidelity modeling and is frequently updated to remain current as the reactor and plant design progress.

The simulator was critical to the success of the SPV testing. NuScale will continue to maintain and update this critical asset for use throughout integrated system validation (ISV) testing.

4.2.1 Simulator Software

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4.2.2 Module Control System Layout and Workstation Design

The NuScale conceptual control room includes the following attributes:

- bank of VDUs configured with SDCV HSIs safety (PAM) variables is referred to as the safety display and indication (SDI) panel
- sit-down workstations for three reactor operators, each able to access HSIs for all individual units and common plant systems
- sit-down workstations for three senior reactor operators (SM, STA, CRS)
- a dedicated stand-up workstation for each unit to allow for focused operation of that unit, including the “manual” backups (hardwired switches) for system level actuation and other protective functions
- a dedicated workstation for shared or common systems
- technologies to support teamwork and communications, including enhanced individual and group plant notification techniques and non-wireless communication such as standard phone, verbal and e-mail protocols
- HSIs displayed on the VDUs are navigable and contain the alarms, controls, indications, and procedures necessary to monitor and manage any unit chosen by the operator during normal, abnormal, emergency, and shutdown.
- HSI displayed on the GVDs is SDCV information and are not navigable
- multiple units may be controlled by a single operator at any sit-down workstation simultaneously due to high levels of automation and passive safety functions

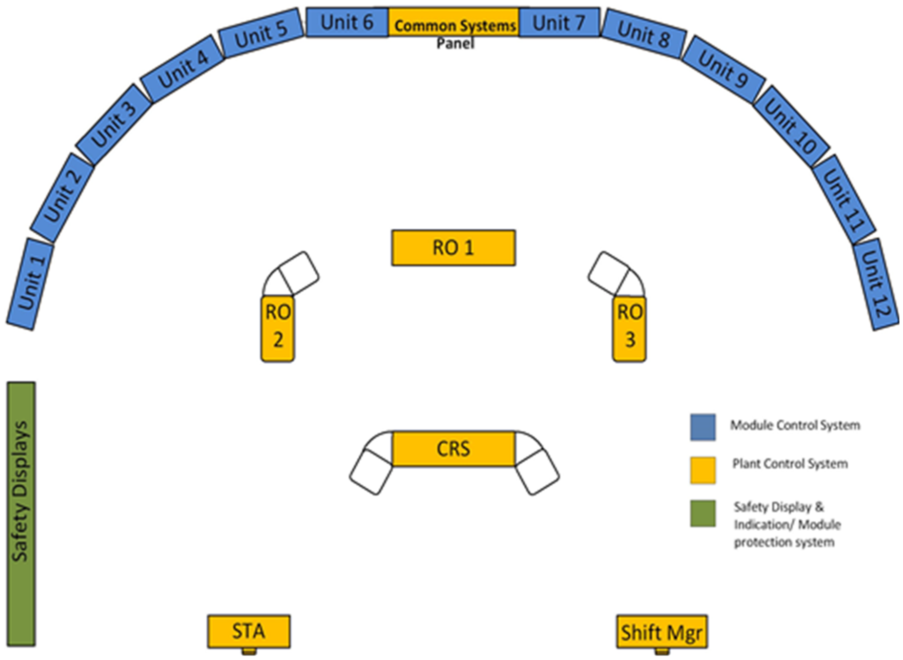

Figure 4-1. NuScale main control room layout concept

4.2.2.1 Stand-Up Unit Workstations

The MCR contains 12 stand-up unit workstations. Each stand-up workstation has five VDUs, a keyboard, a mouse, and manual switch backups for protection functions. The unit overview display VDU is a GVD that provides SDCV unit status information to MCR personnel. The unit overview display does not have navigation capabilities. The HSIs displayed on all four lower VDUs are navigable and contain the alarms, controls, indications, and procedures necessary to monitor and manage the corresponding unit during normal, abnormal, emergency, and shutdown operations. The function of the four lower VDUs may be accomplished by other means providing the operators utilizing the workstation can view four independent HSI display pages simultaneously. The GVD must remain independent and non-navigable.

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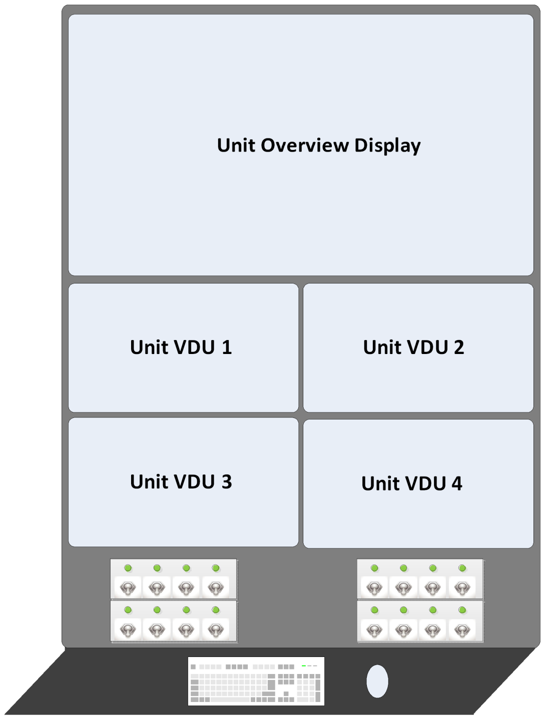

Figure 4-2. Stand-up unit workstation

4.2.2.2 Common Systems Workstation

The common systems workstation includes a keyboard, a mouse, and six VDUs that provide HSIs for alarms, controls, indications, and procedures for systems common to all 12 units (e.g., electric plant, reactor pool cooling, instrument air, reactor building and radwaste building ventilation, radioactive waste systems, radioactive waste drain system, demineralized water system, fire protection system, and communications system).

The common system plant overview GVD displays the plant status information needed to support the safe operation of the plant and provide a common location for the crew to monitor plant status.

The function of the six lower VDUs may be accomplished by other means providing the operators utilizing the workstation can view six independent HSI display pages simultaneously. The GVD must remain independent and non-navigable.

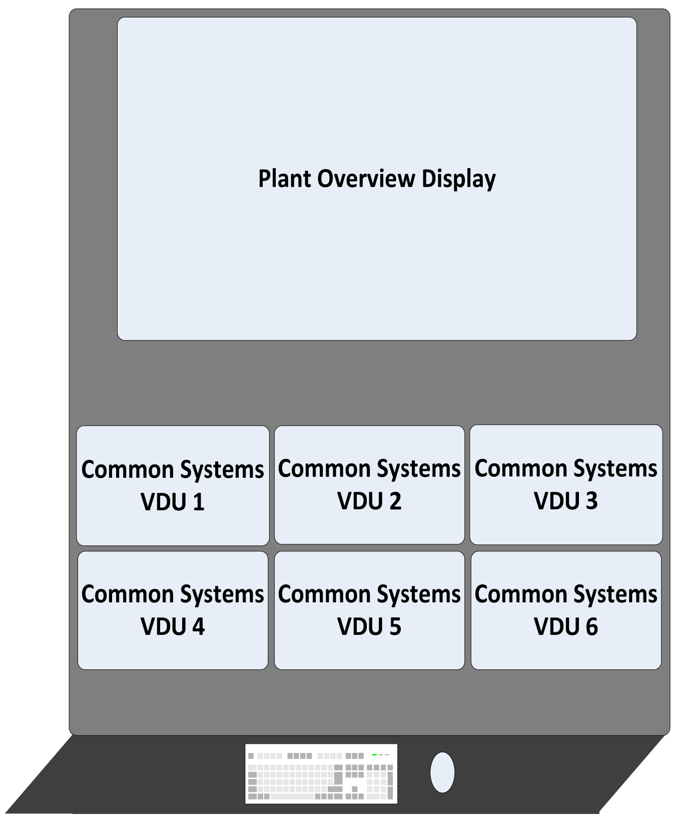

Figure 4-3. Common systems workstation

4.2.2.3 Sit-Down Workstation

Each sit-down workstation has at a minimum four VDU, a keyboard and a mouse as shown in Figure 4-54. The HSIs displayed on those VDUs contain the alarms, controls, indications, and procedures necessary to monitor and manage any unit chosen by the operator during normal, abnormal, emergency, shutdown, and operations. A single operator can control multiple units simultaneously.

The function of the four VDUs may be accomplished by other means providing the operators utilizing the workstation can view four independent HSI display pages simultaneously.

The MCR operators and supervisors interface with the plant at their designated workstations using HSI software located on the plant control system (PCS) and MCS networks. Due to high levels of automation and passive safety functions, multiple units may be controlled by a single operator at any workstation simultaneously. Additionally, common or shared plant systems are able to be fully monitored and managed from each workstation. The capability of the HSI and the supporting PCS and MCS network architecture structure allows the operator workstations to support oversight and control activities.

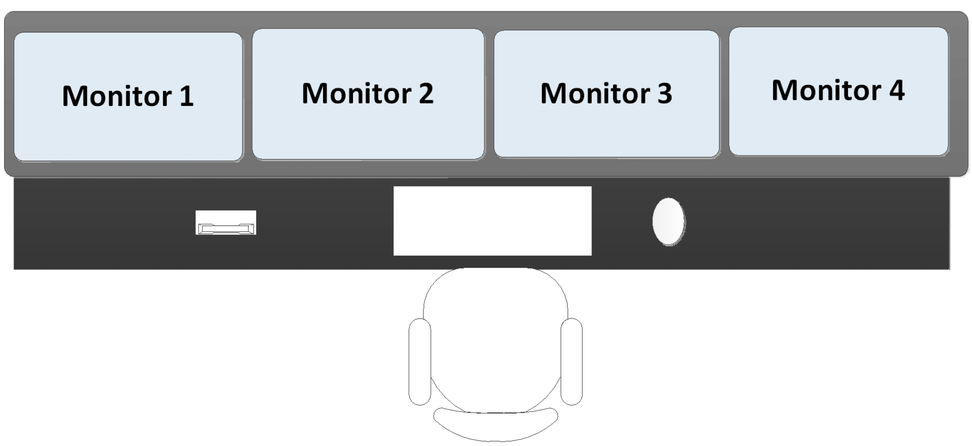

Figure 4-4. Sit-down workstation

4.2.2.4 Safety Display and Indication Panel

The SDI bank of SDCV VDUs provides redundant, highly reliable indications of plant conditions. Operators rely on these indications to give them the status of the plant even in conditions where normal power and backup power have been lost for an extended period of time. {{

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Figure 4-5. SDI panel

4.3 Human-System Interface Design Overview

The NuScale HSI design incorporated pertinent design considerations based on accepted HFE principles and industry standards. In addition, the design incorporated high-level design considerations identified during preliminary analyses such as; maintaining situational awareness with a highly automated system and acceptable workload levels with multiple modules assigned to a single operator.

Within the HSI design process, there were common design elements that drove the entire architecture and usability of the user interface. The elements, below, are discussed in detail in subsequent subsections.

- Survey of state-of-the-art in HSI technologies

- Develop an HSI global layout and navigation schema
- Develop notification schema
- Develop procedures
- Develop automated process

4.3.1 Survey of State-of-the-Art in Human-System Interface Technologies

There is no single solution to every HSI design situation; therefore, the HSI Style Guide maintains consistency when design decisions require a unique situation. The following summarizes the results of a few key survey issues.

The HFE design team investigated the use of the following state-of-the-art technologies for use in the NuScale HSI design:

- mouse cursor-based interaction
- process and information visualization techniques
- abstraction hierarchy-based presentation (i.e., multiple levels of detail)
- techniques for facilitating navigation and orientation, including windowing
- direct manipulation interfaces and soft controls
- alarm filtering and prioritization systems
- computer-based procedures

1. The HSI design primarily uses mouse-based technology with touch screen being considered for future enhancements.
2. The organization and presentation of information is critical in designing a display for safety-critical systems. The effect of functional organization and the choice of information presentation styles (process display vs. functional display), parameter presentation (text vs. bar chart), and component presentation (mimic vs. simplified graph) were considered.

   Listed below are the HSI Style Guide (Reference 6.2.2) guidelines that address the evolution of the HSI and the decisions made to improve the interface.

   (1) **NuScale Guideline Title:** Operator Information Linking, NuScale HSI Style Guide, ES-0304-1381-7925.

   (2) **NuScale Guideline Title:** Visual Representation of Path, NuScale HSI Style Guide, ES-0304-1381-9188.

(3) **NuScale Guideline Title:** User Verification of Higher-Level Information, NuScale HSI Style Guide, ES-0304-1381-7933.

3. All techniques for facilitating navigation and orientation of the system (formats, terminology, grouping, windowing and operator's decision-support aids) reflect a clear logic based on task requirements. Each display, control, and data-processing aid to the overall task/function was made such that operators can recognize where they are in the data space and rapidly access data not currently visible (e.g., on other display pages).

   Listed below are the HSI Style Guide (Reference 6.2.2) guidelines that address proper menu and navigation design.

   (1) **NuScale Guideline Title:** Menu Design, NuScale HSI Style Guide, ES-0304-1381-9116.

   (2) **NuScale Guideline Title:** General List of Menu Options, NuScale HSI Style Guide, ES-0304-1381-9002.

4. Direct manipulation interfaces allow users to act on visible objects to accomplish tasks, e.g., opening a display by clicking on its icon. Icons shown on mimic displays represent specific plant components, systems, or functions. Clicking on them may provide access to information about these components and systems, or display an interface for their operation. Input is provided by using a pointing device to manipulate the graphical object, causing the computer operations to be performed on the object or information it represents.

5. The basic function of soft control systems is to provide operators with control interfaces that are mediated by software rather than by direct physical connections. The HFE design team used the guidance provided in the “Soft Controls” section of Reference 6.2.2 for the implementation of soft controls.

6. The HFE design team created an alarm filtering and prioritization schema for the plant notifications. This schema is discussed below in the HSI Concept of Use section of this RSR.

7. The traditional computer-based procedures are being developed for the NuScale plant for use during the ISV testing phase. The embedded procedure schema that NuScale designed is discussed in Section 4.3.4.

4.3.2 Develop a Human-System Interface Global Layout and Navigation Schema

A well-designed navigation schema is critical to support the goal of reducing the number of operators in the NuScale MCR. The navigation design incorporates the organization of shared information, screen content, and labeling schemes in a way that is easy for the operators to find, understand, and manage.

The navigational design developed utilized a global architecture that works to incorporate the navigational look and feel throughout the library of pages. When developing the TA and associated conceptual sketch, attention was paid to where and how the navigation development fit within the navigation organizational structure as shown in Figure 4-6.

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Figure 4-6. Example of a navigation schema

Developing more than one path to a desired HSI element achieves a goal of the HFE design team. Operators react and respond differently while trouble shooting a problem so the HSI navigation should not restrict the operator to follow a single-minded solution. By providing multiple navigational paths, the operators have the freedom to choose a path that best matches their mental model.

4.3.3 Develop Notification Schema

Plant notifications are a vital piece of the HSI design. It must aid the control room staff in understanding the current plant status without creating distracting clutter. The NuScale notification icons are shown below and discussed further in the HSI Concept of Use section of this RSR.

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Figure 4-7. NuScale notification alarm, caution and notice icons

4.3.4 Develop Procedures

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4.3.5 Develop Automated Processes

Due to the fact that most processes and transitions in a NuScale plant are controlled by automation, an automation interface schema was developed. The schema developed includes how operators will interact with the automation processes to provide limits, ensure prerequisites, initiate changes, secure evolutions, and monitor additional process elements as the design matures.

4.3.6 Conceptual Sketches

A conceptual sketch is a two-dimensional illustration of an interface that specifically focuses on space allocation and prioritization of content, functionalities available, and intended behaviors. For these reasons, conceptual sketches typically do not include any styling or graphics. Conceptual sketches also help establish the relationships between an application and its various screen templates. An example of a conceptual sketch is shown in Figure 4-8.

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Conceptual sketches serve multiple purposes by helping to:

- communicate and explore the concepts that come out of sketching the system.
- connect the system page to the HSI library navigation schema.
- clarify consistent ways for displaying particular types of information on the system page.
- determine intended functionality in the interface.
- prioritize content through the determination of the amount of space to allocate to a given item and where that item is located.

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Figure 4-8. Example of a conceptual sketch

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Figure 4-9. Example of a HSI display page

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4.3.7 Rapid Prototyping and Trade Off Evaluations

While the simulator provides a realistic user experience with the system, the focus in this effort is on rapidly testing design concepts and soliciting feedback. Rapid prototyping centers around capitalizing on the simulator's ability to provide a platform where software code and hardware layouts can be quickly evaluated and dismissed or modified in fast subsequent development iterations.

4.3.8 Human-System Interface Design Evolution

Phase 1 and 2 of the simulator development effort focused on significant software code changes that developed the data exchange between the HSI and the plant models. As a result, the HSI did not change with respect to the graphics, just the connectivity to the models. Efforts to format the HSI began in Phase 3 with the creation of the HFE design team and the start of weekly simulator team meetings. During each phase of the development, a list of changes and the reasons for those changes was discussed.

Note: Only the display page elements that the HFE design team deemed relevant to the HSI design evolution and implementation process were discussed.

4.3.8.1 Display Page Evolution

During Phase 3, the HFE design team focused on the page navigation schema and overall HSI page design. The goal was to design an HSI that provided a common look and feel with an SDCV navigation interface. Following this concept would provide the operators with easy to use HSI that provides continuous access to the navigation buttons regardless of which page is displayed. {{

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Figure 4-10. Phase 3 human-system interface design evolution

Phase 4 of the design focused on the HSI layout by performing early task support verification and enforcing the newly developed HSI Style Guide. As a result, more required information and consistency was added to the use of colors and icons. {{

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Figure 4-11. Phase 4 human-system interface design evolution

Phase 5 of the design created a more simplistic and easier to use interface. The design team determined that the Phase 4 display was cluttered and the navigation interface was becoming cumbersome, so the design team made the decision to provide {{

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Figure 4-12. Phase 5 human-system interface design evolution

Phase 5.3 of the HSI design was primarily inspired by the scenario development and testing leading up to the staffing validation effort. {{

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While these particular touch points do not meet the style guide requirements for size, the design team has waived that requirement here because it is a secondary means of accessing the system page.

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Figure 4-13. Phase 5.3 human-system interface design evolution

4.3.8.2 Unit Group View Display Evolution

This particular HSI page is individually discussed due to the significant role it plays in the success of the NuScale staffing qualification effort. All evolutions mentioned in the Display Page Evolution section above apply to the GVD evolution with a few unique characteristics about the GVD page added below.

Phase 3 of the GVD page was developed to test out many options that the team thought would be needed by the operation crew. During the first phases of the simulator layout many parameters, icons, and alarm tile concepts were evaluated on the GVD while the plant models were being developed and tested. The large format of the GVD allowed the team to evaluate many ideas at once for their inclusion on the GVD and elsewhere in the HSI library.

The GVD is a SDCV page that will not have any navigation capabilities. Its purpose is to provide unit specific information needed by the operating crew to safely operate the plant. {{

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Figure 4-14. Phase 3 unit group view display page

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Figure 4-15. Phase 4 unit group view display page

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Figure 4-16. Phase 5 unit group view display page

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Figure 4-17. Phase 5.3 Unit group view display page – normal operations

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Figure 4-18. Phase 5.3 Unit group view display page – shutdown operations

4.3.9 Color Selection Chart

The NuScale software design team has two HSI software designers with color vision deficiency. This allowed the HFE design team to create and test a color palette that serves users with similar color vision deficiencies.

4.3.10 Chevron Icon

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Figure 4-19. Chevron icon

4.3.11 Reactor Module Icon

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Figure 4-20. RXM icon views 1

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Figure 4-21. RXM icon views 2

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Figure 4-22. RXM icon views 3

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Figure 4-23. RXM icon view 4

4.4 Human-System Interface Concept of Use

The operating crew is responsible for the safe operation of the plant and maintaining power production. This section discusses how the HSI design helps the crew communicate amongst themselves and with other members of the staff outside of the MCR.

The HSI design provides intuitive HSIs and supervisor oversight that minimizes personnel errors (e.g., performing the right action on the wrong module) and supports error detection and recovery capability. Some of the attributes of the HSI are listed below and discussed in greater detail in the following subsections.

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Figure 4-24. Stand-up unit labeling example

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Figure 4-25. Main navigation bar labeling example

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Figure 4-26. Control element pop-up window

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Figure 4-27. 12 unit overview

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Figure 4-28. Safety function monitoring page

4.4.1 Direct Component Operation

NuScale HSI system display pages were created using the system PI&D and TA. The pages have the capability to control the components needed to successfully complete tasks and monitor parameters needed to maintain safe operation of the plant. The Chemical Volume and Control System page is shown below as an example of a typical NuScale HSI display page.

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Figure 4-29. Chemical volume and control system display page

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4.4.2 Embedded Procedures

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Figure 4-30. Process library page

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Figure 4-31. Process library page showing an embedded procedure

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Figure 4-32. Process library – active process progress bar

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4.4.3 Automation Interface

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Figure 4-33. Process library – showing automation

4.4.3.1 Continuous Monitoring

A key HSI feature associated with automated operation is to enable performance monitoring by operators. The HSI enables operators to manage automation by providing the necessary information, displays, and controls to enable support observation, independent verification, and operator intervention. For example, if automation is monitoring or controlling a parameter, operators have access to observe the setpoints for action and consequential actions should the setpoint be reached. If the setpoint allows for operator adjustment, then the operator may intervene and adjust appropriate setpoints within allowable limits.

4.4.3.2 Repetitive Tasks

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4.4.3.3 High Cognizant Burden Functions

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4.4.3.4 Startup and Shutdown

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4.4.3.5 Power Maneuvering

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4.4.3.6 Primary System Process Control

Key reactor coolant parameters are continuously monitored by automation. When one of these parameters approaches the administrative limit, the automation responds. Depending on the parameter, the associated automation may respond with or without operator involvement.

Reactor pressure control at normal operating pressure is an example of primary system process control without operator involvement. As described above under continuous monitoring, operators may elect to monitor the pressure controlling automation performance at any time. The automation controlling pressure does so without direct operator involvement. The operator may elect to take manual control, such as for drawing or collapsing the pressurizer steam bubble or changing the control pressure during automatic operation.

Boron concentration control is an example where operator control may be used. The automation monitors dilution and boration history, average coolant temperatures, pressurizer level, core age, historical power, and boron concentration data to generate recommendations for dilution or boration. When the automation detects conditions warranting a dilution or boration, the automation notifies the operator with an action recommendation and recommended limits. Supporting the recommendation, the automation provides the supporting basis for this recommendation, thereby facilitating the operator’s evaluation of the recommendation.

The operator may elect to take no action, accept the recommendation, or modify the recommended dilution/boration/letdown actions within the recommendation limits. Once the automation begins performing the sequence, the operator may abort or alter the sequence at any time.

4.4.4 Shared Roles

4.4.4.1 Parameter Monitoring

Automation performs functions associated with parameter and process monitoring, defined sequence functions, continuous process control, alert and alarm monitoring, safety limit monitoring, and automatic safety functions. Operators monitor and evaluate automated functions, intervening as required. Operators may also elect to share control with the automation or assume control of the automated function.

Generally, operators observe process parameters being monitored by automation. This shared role of process monitoring supports situational awareness and enables the operator to evaluate automated system performance. Operators increase attention to performance monitoring when

- transients are anticipated.
- an automated operation needs to be confirmed.
- degraded automation is suspected.

4.4.4.2 Operator Intervention

Operators intervene when it becomes apparent that the automation has failed or when the automation is no longer appropriate for the current or planned plant conditions. The criteria for operator intervention involve judgment of continued safe operation of the plant.

4.4.5 Plant Notifications

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}}2(a),(c)

4.4.5.1 Functional Specifications

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}}2(a),(c)

4.4.5.2 Tiered System

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}}2(a),(c)

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4.4.5.3 Personnel Response

Operators respond to all notifications promptly regardless of type. The type only impacts the operators' response to a notification when more than one notification is received. Emergent alarms are addressed before cautions, and cautions are addressed before notices, etc.

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}}2(a),(c)

4.4.5.4 Plant Notifications Human-System Interface Implementation

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}}2(a),(c)

Figure 4-34. Main navigation bar with notifications circled

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4.4.5.5 Alarm Definition and Criteria

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}}2(a),(c)

4.4.5.6 Navigation and Alarm Response

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}}2(a),(c)

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}}2(a),(c)

Figure 4-35. NuScale non-active alarm icon

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}}2(a),(c)

Figure 4-36. NuScale active alarm icon

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}}2(a),(c)

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}}2(a),(c)

Figure 4-37. NuScale acknowledged alarm icon

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}}2(a),(c)

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}}2(a),(c)

Figure 4-38. NuScale cleared alarm icon

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}}2(a),(c)

Figure 4-39. Summary of NuScale alarm icon behavior

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}}2(a),(c)

4.4.5.7 Caution Definition and Criteria

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4.4.5.8 Navigation and Caution Response

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Figure 4-40. NuScale active or acknowledged caution icon

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}}2(a),(c)

Figure 4-41. NuScale cleared caution icon

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}}2(a),(c)

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}}2(a),(c)

Figure 4-42. Summary of NuScale caution icon behavior

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4.4.5.9 Notice Definition and Criteria

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}}2(a),(c)

Figure 4-43. NuScale notice icon

4.4.5.10 Status Indication Definition and Criteria

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}}2(a),(c)

Figure 4-44. Example of a NuScale icon tagged-out status indicator

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4.4.5.11 Event Definition and Criteria

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}}2(a),(c)

4.4.5.12 Integration with other Human-System Interface Elements

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4.4.5.13 Safety Function Monitoring Page

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}}2(a),(c)

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}}2(a),(c)

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}}2(a),(c),ECI

Figure 4-45. Safety function monitoring page example

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}}2(a),(c)

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}}2(a),(c),ECI

Figure 4-46. Safety function monitoring page with notifications

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}}2(a),(c)

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}}2(a),(c),ECI

Figure 4-47. 12 unit overview page displaying the safety function notifications

4.4.6 Operations Crew Interaction

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}}2(a),(c)

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}}2(a),(c)

Figure 4-48. Example operator active and passive control icons

4.5 Human Factors Engineering/Human-System Interface Design Guidance

4.5.1 NuScale Human-System Interface Style Guide Description

4.5.1.1 Introduction

The NuScale Human-System Interface Style Guide promotes design consistency of human interface design components throughout the plant. The primary users of the style guide are:

- the NuScale Plant Operations group
- simulator Plant Modeling engineers
- HFE/HSI engineers
- display page developers
- I&C engineers
- System engineers

The initial design and development of the MCR and the individual workstations located within the MCR follow the style guide's requirements and guidelines. Additionally, the designers apply the appropriate level of HFE fundamentals to design an intuitive, user-friendly work environment and simple but informative HSI display pages.

This style guide was primarily developed by integrating requirements and guidelines from NUREG-0700 (Reference 6.1.1). Other accepted commercial HSI and military HFE design standards were reviewed, and are properly referenced where appropriate.

The development of the guide fulfills the NUREG-0711 (Reference 6.1.2) guidance to ensure the implementation of HFE/HSI principles in the development of NuScale HSI display pages, work locations and workstations. The inclusion of early and continuous HFE activities, as defined in the style guide, throughout the entire design process results in safer and more reliable operation of the plant. It provides the baseline design verification needed for a combined license application.

This document is a living document, meaning changes will be made during the HSI design and verification and validation (V&V) process. Version control is provided through the use of the requirements management software tool, Dynamic Object Oriented Requirements System (DOORS).

4.5.1.2 Purpose

The purpose of this document is to provide a single NuScale Power oriented and easy-to-use source of human factors and human system interface guidance. It consolidates guidance from the source materials of several government and commercial agencies and provides one reference for application to NuScale Power plants. It primarily draws upon NUREG 0700 guidance, but does selectively draw from other documents oriented to other agency missions and adapts and expands upon them to meet the needs of the NuScale Power plants missions and systems

The style guide is intended to promote consistency and user interface best practices across all aspects of the NuScale HSI design that impact the intended user's ability to successfully perform tasks and achieve operational goals. This includes any workstation informational display pages and controls. The scope of this standard covers all aspects of the overall plant design including:

- the human system interface (display pages) for control panels
- environmental considerations including ambient noise levels, temperature, lighting
- communications including public address, telephones, microphones, email, and text
- electronic document support including tech manuals, training, and on-line help
- input devices such as touch screens, laptops, tablets, mice, trackballs, joysticks, and cameras
- output devices such as laptops, tablets, printers, plotters, and video screens
- hardware such as physical switches, knobs, gauges, and analog and digital meters
- anthropometric and ergonomic considerations for the immediate work area

These aspects of the plant design combine to create the total user experience and contribute to the user's ability to efficiently, effectively, and accurately complete tasks. The style guide is written to help optimize the interaction of these elements of design.

4.5.1.3 Promote Consistency

The NuScale HSI Style Guide promotes the creation of user interfaces that are consistent throughout the plant. When user interface consistency is achieved for similar work across all users, ease of use and ease of learning will be significantly improved. The style guide addresses both work location and workstation user interface design consistency and is intended for use by the HFE design team as part of a comprehensive HSI process.

4.5.1.4 Increase Awareness of the Importance of Human Factors Engineering and Human-System Interface

The HSI Style Guide increases awareness and understanding of the importance of integrating HSI processes and HSI design requirements into the design and development for the NuScale plant design. The benefits of applying HSI processes and HSI design requirements early in the development cycle is that it promotes consistency and efficiency, which provides a cost advantage for the design, operation, and overall lifecycle of the plant, including standardization of maintenance and training.

4.5.1.5 Applicability

The requirements and guidelines are applied to design and development efforts for the NuScale Power plant. The HFE design team utilizes the style guide standards in the design of operator workstations and the locations they are managed from.

The HFE design team created the NuScale HSI Style Guide (Reference 6.2.2) early in the simulator development effort to be continuously applied throughout the design lifecycle thereby serving as the set of guidelines and requirements meant to drive display page consistency and incorporate lessons learned from previous design efforts. The style guide is unique in that it represents more than just a collection of HFE/HSI requirements. The style guide is designed to supply the users of the document all of the information, requirements, functional specifications, and examples in one location.

The NuScale HSI Style Guide consists of three volumes and a set of appendices as discussed and shown below.

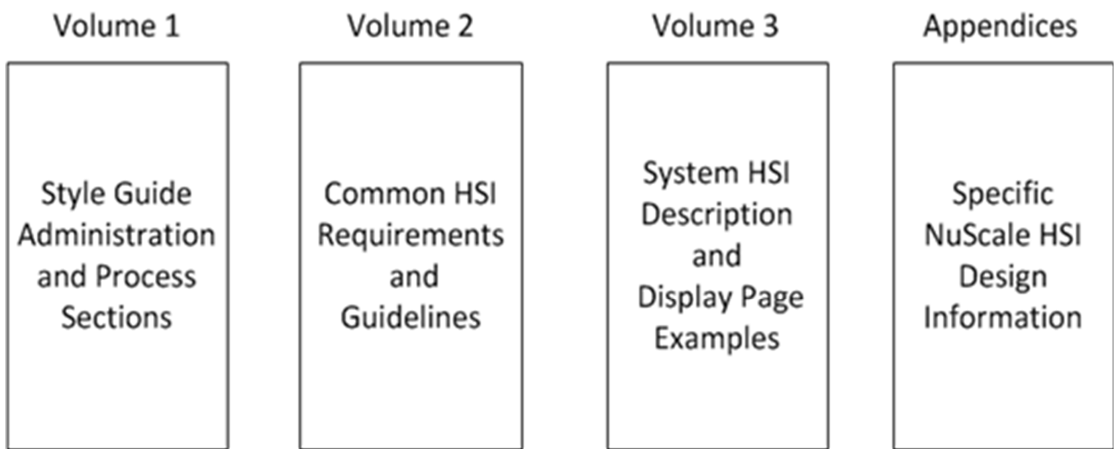

Figure 4-49. NuScale human system interface style guide organization

4.5.2 Volume I Style Guide Administration and Process Sections

Volume I provides administrative and background information for the HSI stakeholders, system engineers, and management. Any information that describes how to use the HSI Style Guide and all reference documents used to create the style guide are included in this volume.

Chapter topics include but are not limited to:

- purpose and organization of the volumes
- intended users/stakeholders
- process for change within the volumes
- process for using Volume II, Volume III and the appendices to design and develop HSI display pages

4.5.3 Volume II Common Human-System Interface Requirements and Guidelines

Volume II provides the users with a single, common set of HSI guidelines and requirements that are system independent. All sources are consolidated into this volume and include the adjudication of the differences, where necessary.

The sources, at a minimum, include:

- NUREG 0700
- ANSI and HFES

4.5.4 Volume III System Human-System Interface Description and Display Page Examples

Volume III provides the HSI Library that reflects the implementation of Volume II. The volume will contain chapters comprised of specific information about a system, location, or concept in a NuScale Plant. Volume III will be provided to a combined operating license applicant (COLA) upon request.

Chapter topics include but are not limited to:

- system overview and scope
- definitions
- system specific information
- HSI display page information
- symbols
- icons
- objects
- workstation construct where applicable
- system display page examples
- work location specific information (MCR, TSC, RSS, EOF and local control station (LCS))

4.5.5 Appendices Specific NuScale Human-System Interface Design Information

The appendices have been created as designer guides that address key HFE and HSI design elements. Their use drives consistency and commonality throughout the project.

- Appendix A – Language and Text
- Appendix B – Color Usage
- Appendix C – User Interfaces
- Appendix D – Display Page Design
- Appendix E – Plant Notifications
- Appendix F – Safety Display and Indication System
- Appendix G – HFE Design
- Appendix H – Automation and Computer-based Procedures

4.5.6 Concept of Operations

The concept of operations provides an overview of the supporting processes, individual roles, operations staffing, crew structure, and operating techniques that will be used by the operating crews of a NuScale facility to achieve safety and production goals.

4.5.7 Conduct of Operations

The conduct of operations provides a set of standards to influence operator behaviors to ensure high quality, consistent, task performance that supports the safe and reliable operation of the NuScale plant. This is applicable to all on-shift operations staff.

4.6 Human-System Interface Detailed Design and Integration

4.6.1 General Considerations

In addition to the input elements discussed in Section 4.1, the HSI process also took into consideration the design elements listed below. HFE issues initiated and tracked in HFEITS during the analyses performed with the NuScale simulator (testbed) were evaluated during HSI design and incorporated as appropriate.

4.6.1.1 Important Human Actions

The NuScale HSI design minimizes the probability of error in the performance of IHAs and provides the opportunity to detect errors, should they occur. A minimum of two actions are required for all VDU controls (e.g., an action to call up the control function on the VDU (a pop-up window) and an action to actuate the control). This two-step actuation technique reduces the potential for erroneous operator actions that could cause a transient.

4.6.1.2 Human-System Interface Layout Bases

The layout of workstations (number and location of VDUs) in the MCR, the arrangement or hierarchy of the individual HSI screens for each workstation, and the arrangement of the workstations within the MCR are based on job analysis, an understanding of the frequency and sequence of use (e.g., considers procedures for startup, shutdown, normal operating, abnormal operating, and accident situations), and the roles defined for operators during S&Q analysis. The HSI layout in the MCR is specifically designed to support staffing during all operating plant modes. Shared system VDUs and unit and plant overview VDUs are located such that they can be observed from multiple locations within the MCR. Unit workstations are spaced so that side-by-side operation at adjoining units allows sufficient elbow room.

4.6.1.3 Human-System Interface Support for Inspection, Maintenance, and Testing

The NuScale HSI is designed to support inspection, maintenance, test, and repair of plant equipment. The IRM system is used to control work and manage component tagging for out-of-service conditions. IRM information is used (directly or indirectly) to communicate status information to the HSI, which uses the shading and a color scheme to alert the operators of those conditions on the system display VDUs.

Figure 4-50 shows the most current notification examples of possible states or conditions that a control element can have in a NuScale plant. As the HSI design evolves, this list may change if different solutions or new conditions are discovered.

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}}2(a),(c)

Figure 4-50. Example of NuScale icon status indicators

4.6.1.4 Support for Staffing Conditions

The NuScale HSI supports minimum staffing. The passive features, modular design, and high degree of automation reduce the number of alarms, controls, indications, and procedures. The automation, along with the reduced task burden of managing the HSI, enhances the ability of operators to maintain SA of overall plant conditions. The use of minimum staffing to operate the plant safely was confirmed through the analysis of IHAs, TA, and S&Q.

In addition, the HSI design activity included the MCR facility, which is the result of HSI design and has been validated for the conditions included in the SPV scenarios.

4.6.1.5 Human Performance/Fatigue

The NuScale HSI is designed to enhance human performance by reducing fatigue. Automation of plant functions reduces repetitive tasks. Reduced navigation between individual screens is accomplished by simplified plant design. The arrangement or hierarchy of individual HSI screens is based on job analysis, the frequency and sequence of use, and operator roles to increase the simplicity of navigation. Task-based displays are incorporated to reduce navigation steps during procedure use. VDUs are designed for pointing device (e.g., mouse) operation.

In addition, the detailed design conducted during the HSI design element optimizes MCR facility attributes that are known to affect fatigue, such as lighting, ergonomics, and overall physical layout.

4.6.1.6 Environmental Conditions

MCR environmental conditions comply with Regulatory Guide 1.196 with regard to temperature, humidity, air quality, and radiation protection. Auxiliary systems such as heating, ventilation, air conditioning, and lighting systems are designed by other engineering disciplines with input from the HFE design team.

4.6.1.7 Human-System Interface Updates of Plant Modifications

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}}2(a),(c)

4.6.2 Main Control Room

The HFE design team ensured that the HSI process and the resulting products addressed the following important MCR considerations:

1. Safety Display and Indication Console

The NuScale HSI design addresses the 10 CFR 50.34(f)(2)(iv) requirement to provide a plant safety SDI console that will display to operators a minimum set of parameters defining the safety status of the plant, capable of displaying a full range of important plant parameters and data trends on demand, and capable of indicating when process limits are being approached or exceeded as discussed below.

The NuScale PRA, Safety Analysis, and Plant Operations groups considering the guidance of NUREG-1342 determined the critical safety functions. The selection of the variable type (A, B, C, D, or E) was performed. The minimum set of parameters chosen for display are available on the SDCV SDI display panel for each unit in the MCR. An SDI Display page example is shown in Section 7.0.

Note: There are no Type A variables in the NuScale plant design or E variables shown on the SDI HSI.

2. Bypassed and Inoperable Status Indication

The NuScale HSI design addresses the bypassed or inoperable status indication (BISI) function 10 CFR 50.34(f)(2)(v) requirement to provide for automatic indication of the bypassed and operable status of safety systems as discussed below.

The HSI continuously monitors the operability and position status of the components supporting the plant safety related functions. The HSI updates the information on the appropriate system display pages and for the SDCV locations. {{

}}2(a),(c)

3. Relief and Safety Valve Position Monitoring

The NuScale HSI design addresses the 10 CFR 50.34(f)(2)(xi) requirement to provide direct indication of relief and safety valve position (open or closed) in the control room as discussed below.

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4. Manual Feedwater Control

10 CFR 50.34(f)(2)(xii) refers to a safety-related auxiliary feedwater system that is not applicable in the NuScale plant.

5. Containment Monitoring

The NuScale HSI design addresses the 10 CFR 50.34(f)(2)(xvii) requirement to provide instrumentation to measure, record and readout in the control room: (A) containment pressure, (B) containment water level, (C) containment hydrogen concentration, (D) containment radiation intensity (high level), and (E) noble gas effluents at all potential, accident release points as discussed below.

The HSI provides containment vessel pressure, water level, and radioactive release path {{

}}2(a),(c)

Note: The underlying purpose of the containment hydrogen monitoring requirements of 10 CFR 50.44(c)(4), and 10 CFR 50.34(f)(2)(xvii)(C) is to:

1) identify and assess core damage during and following an accident, and
2) assess containment combustible gas conditions to determine if mitigating actions are required.

NuScale is seeking an exemption from supplying this parameter based on:

3) This parameter is not needed because the NuScale design is relying on the under Bioshield Radiation monitors to provide core damage assessment capabilities
4) Due to the fact that the possibility of damage to a subatmospheric containment from hydrogen is remote
5) With the NuScale design there is abundant time to assess and mitigate hydrogen generation if required

6) The NuScale design provides alternate means of indirectly measuring containment hydrogen

6. Core Cooling

The NuScale HSI design addresses the CFR 50.34(f)(2)(xviii) requirement to provide unambiguous indication of inadequate core cooling, such as primary coolant saturation meters in pressurized water reactors (PWR), and a suitable combination of signals from indicators of coolant level in the reactor vessel and in-core thermocouples as discussed below.

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}}2(a),(c)

7. Post-accident Monitoring

The NuScale HSI design addresses the CFR 50.34(f)(2)(xix) requirement to ensure the monitoring of plant and environmental conditions following an accident that includes core damage as discussed below.

The HSI provides indication of plant conditions following an accident including core damage on the appropriate SDI display VDU in the MCR. Refer to the Safety Display and Indication System (Item 1 above) for more detail on the type of information displayed at this location.

8. Leakage Control

The NuScale HSI design addresses the 10 CFR 50.34(f)(2)(xxvi) requirement to provide for leakage control and detection in the design of systems outside containment that contain (or might contain) accident-source-term radioactive materials following an accident as discussed below.

The leakage control and detection parameters for systems outside containment are displayed on the SDI, Plant Overview and Containment Evacuation display pages and are available on the workstation VDUs in the MCR.

9. Radiation Monitoring

The NuScale HSI design addresses the 10 CFR 50.34(f)(2)(xxvii) requirement to provide appropriate monitoring of in-plant radiation and airborne radioactivity under a broad range of routine and accident conditions as discussed below.

Radiation monitoring for the NuScale plant is a shared unit system. Thus, the monitoring and display of in-plant radiation and airborne radioactivity for the range of routine and accident conditions is on the common systems panel VDU in the MCR. In addition, the Feed and Condensate and Containment Evacuation display pages contain trends to display this information.

10. Manual Initiation of Protective Actions

As required by Regulatory Guide 1.62, safety system automation override and manual initiation of safety functions during unanalyzed conditions is provided {{

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}}2(a),(c)

Figure 4-51. Hard-wired critical safety function switches

11. Diversity and Defense-in-depth

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Figure 4-52. Hard-wired non-safety enable switch

12. Important Human Actions

The NuScale HFE/HSI design minimizes the probability of error in the performance of IHAs and provides the opportunity to detect errors, should they occur. {{

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13. Computer-Based procedure platform

Procedures are provided to guide operators in all aspects of plant operations at a NuScale plant. Traditional paper-based procedures will be available. The use of computer-based procedures facilitates mobility and enhances operator use. NuScale computer-based procedures are designed in accordance with the guidance in Section 8 of Reference 6.1.2 and Section 1 of D I&C ISG-05 2008.

NuScale investigated several types of computer-based procedure techniques so that the unique need of the plant is satisfied. Complete electronic versions of the paper copies are available on a tablet via the computer-based procedure system. This will help operators outside of the MCR to have mobile versions of all the procedures. The operators inside of the MCR will also have access to this system via a tablet as well as paper-based procedures for back-up purposes.

Note I: Neither the computer-based procedure system, nor the paper-based procedures are part of this RSR discussion.

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}}2(a),(c)

All three versions (i.e., paper, electronic and embedded) of the procedures are available for ISV testing.

4.6.3 Locations outside of the Module Control System

The HSIs in the locations outside of the MCR (TSC, EOF, and the RSS) are all MCR derivatives (i.e., operated from the same platform and connected to the same I&C distributed control system). These HSIs are for information display only meaning no control functions are provided in any of the emergency response facilities.

4.6.4 Local Control Stations Design

The HSIs on the VDU-based LCSs are MCR derivatives. For vendor-supplied LCSs, the NuScale HFE program scope is limited to ensuring that those interfaces adhere as closely as possible to Reference 6.2.2. Inputs from the vendor-supplied LCSs are replicated on the VDU-based HSI on an as-needed basis.

4.7 Degraded I&C and Human-System Interface Conditions

The NuScale plant is controlled with fewer operator actions than current PWRs due to the number of passive safety features, fail-safe components, and the high degree of automation.

The NuScale plant HSI is designed to accommodate specific types of I&C and HSI system failures. Procedures govern operator identification of and response to the various failure modes.

I&C sensor failures are accounted for in the diversity and defense-in-depth coping analysis (Reference 6.2.8). Sensors are redundant within system trains and safety systems have multiple trains. Alarm response procedures guide operator troubleshooting.

Failures of individual HSI VDUs are accommodated for by use of other VDUs at the workstation, by use of another workstation or by use of the stand-up unit workstations. Failures of hardware that lead to loss of all VDUs at a workstation are accommodated by redundant MCR-derivative VDUs in the RSS. Generally, the unit with a failed MCR stand-up workstation is shut down.

Automated functions have manual backup at the MCR workstation. Failures of automation sequences are alarmed in the MCR. Operators also monitor most automation for expected plant response and detect automation failures when plant response is not as anticipated.

Multiple communications systems are included in the NuScale plant design. Failure of one is accommodated by use of another and controlled by procedure.

TA includes consideration of loss of HSIs that support IHAs as discussed in Reference 6.2.6. TA findings are incorporated in the HSI design as described above in the HSI inputs section.

4.7.1 Defense in Depth

Modern control systems rely on digital I&C systems that possess considerably more power and functionality than their analog predecessors. The I&C system senses basic parameters, monitors performance, integrates information, and makes needed adjustments to plant operations. Digital I&C systems enable the precise monitoring of the plant’s performance, thus providing better data to control systems. In turn, improved controls support better performance and offer a means to operate closer to performance limits. The use of digital computer technology in I&C systems could result in safety-significant common cause failures (CCFs). Some of the major concerns are:

- Common mode failures could defeat the redundancy achieved by the hardware architectural structure, and could result in the loss of more than one echelon of defense-in-depth provided by the monitoring, control, and reactor protection, and engineered safety functions performed by the digital I&C systems.
- The two principal factors for defense against common-mode and common-cause failures are quality and diversity. Maintaining high quality will increase the reliability of both individual components and complete systems. Diversity in assigned functions (for both equipment and human activities) equipment, hardware, and software, can reduce the probability that a common-mode failure will propagate.
- Some level of diversity, such as a reliable analog backup is required

From the HSI perspective the two types of CCFs are discussed below.

4.7.1.1 Common Cause Software Failures

A common cause failure is multiple failures attributable to a common cause. A subset of CCF is a software CCF, which is a failure caused by software errors or software developed logic that could defeat the redundancy achieved by hardware architecture. Two basic forms that prevent CCFs in a system are either to reduce coupling factors or to increase the system's ability to resist those coupling factors.

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}}2(a),(c)

4.8 Human-System Interface Tests and Evaluations

4.8.1 Human-System Interface Inventory & Characterization

This section describes the method NuScale uses to perform inventory and characterization of the HSI displays, controls, and related equipment lying within the scope defined by the scenarios discussed in the Control Room Staffing Plan Workload Analysis, RP-1215-20253 (Reference 6.2.10) and capture the required information as discussed in Sections 8.4.6 and 11.4.2 of (Reference 6.1.2).

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A sample of a form is shown in Table A-1.

4.8.2 Human-System Interface Task Support Verification

The purpose of HSI task support verification is to assess HSIs as they support the tasks identified in TA. HSI task support verification confirms that the HSI design accurately reflects the HSI inventory and characterizations required by TA. The scope of this verification includes alarms, controls, indications, and procedures, and supports needed to perform the scenarios selected for ISV through application of the SOC.

The task support verification is based on the most recent TA results. The TA defines the inventory and characterization for the alarms, controls, indications, and procedures needed to execute operator tasks for normal and abnormal plant conditions including manual tasks, automation support tasks, and automation monitoring tasks.

A sample of a form is shown in Table B-1.

4.8.3 Human Factors Engineering Design Verification

The HFE design verification is conducted to confirm that HSI characteristics conform to HFE guidelines as represented in the NuScale HSI Style Guide. The style guide consists of procedures for use, general considerations, and system-specific guidance for screen-based HSIs.

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}}2(a),(c)

A sample of a form is shown in Table C-1 and Table C-2.

4.8.4 Staffing Validation

The S&Q RSR (Reference 6.2.7) includes staffing evaluations for activities performed by licensed control room operators. When licensed operator workload was impacted, the area of concern was analyzed to quantify the impact to licensed operator workload or staffing and to develop any HSI or staffing adjustments required to address the specific task and associated staffing requirements.

For specific details about the staffing validation effort, refer the Control Room Staffing Plan Validation Methodology RP-1215-20253 (Reference 6.2.10).

5.0 Analysis Conclusions

NuScale's integrated HSI design was developed by a multi-faceted HFE design team that brought unique skills and knowledge to the effort and worked collaboratively and cohesively to reach the projects goals. The HFE design team included former nuclear plant operators and supervisors, plant system engineers, I&C engineers, simulator plant model and HSI software developers and human factors engineers. This collaboration drove multi-disciplinary analyses to complex design decisions early in the conceptual design.

NuScale utilized the collective operating experience of its design staff, the FRA/FA, TIHA and TA results, tabletop activities and preliminary simulator observations to determine initial staffing levels. This information helped the team develop the layout and construct the MCR simulator, develop the HSI Style Guide, screen layouts and communications protocols used by the operators during the SPV effort.

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}}2(a),(c)

6.0 References

6.1 Source Documents

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

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

6.2 Referenced Documents

6.2.1 Concept of Operations, RP-1215-10815.

6.2.2 NuScale Human System Interface Style Guide, NP-ES-304-1381.

6.2.3 Human Factors Verification and Validation Implementation Plan, RP-0914-8543.

6.2.4 Human Factors Engineering Operating Experience Review Results Summary Report, RP-0316-17614.

6.2.5 Human Factors Engineering Functional Requirements Analysis and Function Allocation Results Summary Report, RP-0316-17615.

6.2.6 Human Factors Engineering Task Analysis Results Summary Report, RP-0316-17616.

6.2.7 Human Factors Engineering Staffing and Qualifications Results Summary Report, RP-0316-17617.

6.2.8 Diversity and Defense-in-Depth Analysis of the Module Protection System, ER-E00-3530.

6.2.9 Human Factors Engineering Treatment of Important Human Actions Results Summary Report, RP-0316-17618.

6.2.10 Control Room Staffing Plan Validation Methodology, RP-1215-20253.

7.0 HSI Display Page Examples

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}}2(a),(c),ECI

Figure 7-1. Safety function monitoring page

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}}2(a),(c)

Figure 7-2. Plant overview page

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}}2(a),(c),ECI

Figure 7-3. SDI page

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}}2(a),(c),ECI

Figure 7-4. 12 unit overview page

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}}2(a),(c),ECI

Figure 7-5. Unit group view display page

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}}2(a),(c)

Figure 7-6. Process library – automation

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}}2(a),(c)

Figure 7-7. Process library – procedure

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}}2(a),(c)

Figure 7-8. RXM overview page

Appendix A. Human-System Interface Inventory and Characterization Form

Table A-1 shows the form used by the HFE design team to perform preliminary Inventory and Characterization testing. The purpose of this effort was to formalize a process for the testing and verification of the HSI inventory. In this example, the Safety Function Monitoring display page was reviewed. Only the elements needed to successfully complete the SPV testing were evaluated. The same form and process will be followed during ISV testing on every element on the page.

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}}2(a),(c)

This example shows a completed form with no discrepancies found.

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Table A-1. Human-system interface inventory and characterization form

}}2(a),(c)

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}}2(a),(c)

Appendix B. Human-System Interface Task Support Verification Form

Table B-1 shows the form used by the HFE design team to perform preliminary Task Support Verification. The purpose of this effort was to formalize a process for the testing and verification of the HSI inventory. In this example the chemical and volume control system display page was evaluated against the TA for that system. Only the tasks needed to successfully complete the SPV testing were evaluated. Also, only a small portion of the form is shown in order to provide an abbreviated sample of the process. The same form and process will be followed during ISV testing covering all tasks in the TA deemed necessary to complete Task Support Verification.

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This example shows a completed form with no discrepancies found.

Table B-1. Human-system interface task support verification form

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Appendix C. Human Factors Engineering Design Verification Form

Table C-1 and Table C-2 show the form used by the HFE design team to perform preliminary HFE design verification. The purpose of this effort was to formalize a process for the testing and verification of the HSI inventory. {{

}}$^{2(a),(c)}$ The same form and process will be followed during ISV testing covering all new icons, icon enhancements and HSI elements needed to complete HFE Design Verification.

{{

}}$^{2(a),(c)}$

This example shows a completed form with no discrepancies found.

Table C-1. Pump ICON human factors engineering design verification form

Pump ICON Template

PURPOSE: This icon is used to control any of the pumps that are connected to the control system. For SPV, all pumps used the same icon; for ISV, pump icons that more closely resemble the pump type they represent will be used.

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}}2(a),(c)

Table C-2. Valve ICON human factors engineering design verification form

PURPOSE: This icon is used to control any of the valves that are connected to the control system. For SPV, all valves used the same icon; for ISV, valve icons that more closely resemble the valve type they represent will be used.

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}}2(a),(c)

Enclosure 6:

Concepts of Operations, RP-0215-10815-NP, Revision 2, non-proprietary version

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Concept of Operations

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Department of Energy Acknowledgement and Disclaimer

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CONTENTS

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1.0 General Information

1.1 Purpose

The purpose of this report is to describe the concept of operations for the NuScale 12 unit plant design. It describes how the design, systems, and operational characteristics of the plant relate to the organizational structure, staffing, and management framework. It is a key document that supports both the Human Factors Engineering Program Management Plan (Reference 4.2.2) and facilitates meeting the Owners Requirements Document for control room operations related items (Reference 4.2.1).

Commercial plant owner/operators define the operations governing the overall administrative behavior of the plant crew based on the operating preferences. For new designs, a concept of operations document describes human-system interfaces (HSI) and supporting equipment from the perspective of the operators.

This NuScale concept of operations document informs and guides the NuScale design and engineering effort as it relates to the HSI and supporting equipment.

1.2 Scope

The concept of operations provides an overview of the individual roles, operations staffing, crew structure, and operating techniques that will be used by the operating crews of a NuScale facility to achieve safety and production goals. Consistent with NUREG-0711 (Reference 4.2.4) the concept of operations includes:

- Description of operator roles and responsibilities
  - how personnel work with HSIs
  - plant mission including key plant design features that affect the HSI and supporting equipment and operator roles
  - operations crew composition, qualifications, training, command and control
  - operator roles
  - machine agent roles and shared roles
  - communications
- Overview of the HSI and supporting equipment
  - facility layouts
  - workstations, displays, and working positions
  - HSI design features
  - crew interaction with HSI during normal, off-normal, and emergency operations
  - crew interaction with HSI during management of maintenance and modifications

1.3 Abbreviations and Definitions

Table 1-1. Abbreviations

Term	Definition
CRS	control room supervisor
HSI	human-system interface
MPS	module protection system
NLO	non-licensed operator
PCS	plant control system
RO	reactor operator
SM	shift manager
SRO	senior reactor operator
SSC	structures, systems and components
STA	shift technical advisor
VDU	visual display unit

Table 1-2. Definitions

Term	Definition
Agents	The term refers to the human or machine performing a function or functions. An agent monitors the system to detect conditions indicating that a function or task must be performed. An agent assesses the situation, plans a response, and implements it.
Anticipated operating occurrence	Those conditions of normal operations that are expected to occur one or more times during the life of the nuclear power unit and include, but are not limited to, loss of power to all recirculation pumps, tripping of the turbine generator set, isolation of the main condenser, and loss of all offsite power.
Automation	The term refers to automatic machine agents. Automatic machine agents are tasked or initiated by an operator or other automatic machine agent to perform an action or program following a predefined sequence. Levels of automation vary. Some tasks may require little or no operator interaction; other tasks incorporate only partial automation and include high levels of operator involvement.
Boundary conditions	The conditions that clearly identify the operating envelope of the design (i.e., the general performance characteristics within which the design is expected to operate), such as temperature and pressure limits. Clearly identifying boundary conditions helps define the design's scope and interface requirements.
Distracting task	A task of sufficient complexity or duration such that, when engaged in the distracting task, the operator is likely distracted from routine monitoring duties. This term is defined to support the concept of operations and explanation of the at-the-controls operator duties.

Term	Definition
Human System Interface	The human-system interface (HSI) is that part of the system through which personnel interact to perform their functions and tasks. In this document, "system" refers to a nuclear power plant. Major HSIs include alarms, information displays, controls, and procedures. Use of HSIs can be influenced directly by factors such as, (1) the organization of HSIs into workstations (e.g., consoles and panels) (2) the arrangement of workstations and supporting equipment into facilities such as a main control room, remote shutdown station, local control station, technical support center, and emergency operations facility and (3) the environmental conditions in which the HSIs are used, including temperature, humidity, ventilation, illumination, and noise. HSI use can also be affected indirectly by other aspects of plant design and operation such as crew training, shift schedules, work practices, and management and organizational factors.
Information and record management system	This integrated digital system represents the composite features commonly associated with document control, work management, data and information historian, configuration management, and records management.
NSSS	The NSSS is the set of components in a nuclear power plant that produce steam from the core energy production.
Off-normal condition	Conditions to include operating in emergency response procedures, abnormal operating procedures, and alarm response procedures.
Operator	The term refers to a human agent. Typically, the human agent is a licensed reactor operator but may be a licensed senior reactor operator or non-licensed operator.
Procedure	The term refers to a series of actions performed by a human agent. The series of actions may initiate other procedures or sequences.
Repetitive task	A potentially error-likely activity when performed by a human, which involves performing the same action multiple times, because of fatigue or distraction.
Remote Plant Interfaces	A personnel interface for process control that is not located in the main control room.
Sequence	The term refers to a series of actions, programs, subprograms, or subroutines performed by an agent (machine or human). The series of actions may include parallel actions and may interact with other sequences or agents at any time.
Time sensitive task	An activity performed by a human, which, if not completed in the prescribed time, constitutes failure. For example, if there are adverse process consequences should a supply tank go empty, then the manual action to refill that supply tank at low level is a time sensitive task.
Video Display Unit	An electronic device for the display of visual information in the form of text and/or graphics.

2.0 How Personnel Work with Human-System Interfaces

2.1 Plant Mission

The plant mission is the safe, reliable, and cost effective generation of electricity. The mission draws from the relevant staffing goals in the Owners Requirements Document (Reference 4.2.1) and is supported by this concept of operations.

The NuScale Plant Functions are as follows:

- remove fuel assembly heat
- maintain containment integrity
- maintain reactor coolant pressure boundary integrity
- reactivity control
- radioactivity control
- emergency response
- human habitability
- protection of plant assets
- plant security
- power generation

Table 2-1. NuScale Unique Design Features

NuScale Design Feature	Eliminated System or Components
buoyancy forces drive natural circulation of the primary coolant	reactor coolant pumps
reactor core, steam generator, and pressurizer contained within the reactor pressure vessel	reactor coolant system piping pressurizer surge line
reactor pressure vessel housed in a steel containment immersed in water that provides an effective passive heat sink for long-term emergency cooling	residual heat removal system pumps with associated piping and heat exchangers auxiliary feed water system safety injection system

2.1.1 Key Plant Design Features to Inform the Design of the Human-System Interface

Given the unique design features of the NuScale plant, operations are simplified and design goals for the HSI include

- High levels of automation – Optimize the use of automation to reduce human error and free operators to perform higher level control and management functions. Expand the traditional use of remote automatic operation and control into an integrated distributed control system to optimize the human actions and decisions required to achieve and sustain plant safety and reliable power generation.
- Monitoring and control of multiple units in one main control room (MCR).
- Integrated HSI – Optimize the use of information management, automation, alarms, controls, indications, and computer-based procedures to support effective, efficient control in normal, abnormal, and emergency operating conditions as well as during maintenance and modification activities.
- Optimized MCR staff size – Considering the passive safety systems, fail-safe design features, high levels of automation, and minimal important human actions, the staffing level was selected to be safe and reliable when operating a 12-unit plant.

2.1.2 Key Plant Design Features to Inform Operator Roles

- High levels of automation
  - automation of necessary reactivity changes
  - automated startup to maneuver the unit undergoing startup from shutdown to power operations
  - automated shutdown of one unit or multiple units simultaneously
  - automated maintenance of electric power production or return to capacity after grid fluctuations
- Monitoring and control of multiple units in one MCR with acceptable workload levels – units may have different set points, limits, operating conditions, time in fuel cycle, etc.

- Integrated HSI
- Optimized MCR staff size – roles, qualifications, communication techniques, etc.

2.2 Operations Crew Composition, Qualifications, Training, and Command and Control

This section discusses the proposed staffing requirements for a NuScale operating crew, their qualifications, and required training.

The proposed staffing numbers are based on the use of automation, digital operator interfaces, and an efficient plant notification management system. The optimized overall size of the crew is six licensed operators: three reactor operators (ROs) and three senior reactor operators (SROs). The three SROs fulfill the role of shift manager, control room supervisor, and shift technical advisor.

An overview of the proposed NuScale staffing is shown below and used to facilitate HSI and MCR design. In-depth information on the qualifications, training, technical basis, and supporting results for the proposed staffing levels can be found in the staffing and qualifications (S&Q) results summary report (RSR) (Reference 4.2.7).

2.2.1 Operating Crew Composition

Shift Manager (SM) – Each shift has a shift manager that is in charge of overall shift operations. This individual is knowledgeable in all plant disciplines and ensures that the duties of the chemistry, health physics, instrumentation, and other maintenance support services are performed as needed for safe plant operation. The SM is the senior licensed individual assigned to the MCR team and acts as the senior manager on site when the plant manager and operations manager are not available. The SM is the initial person-in-charge to implement the emergency plan. The emergency plan responsibilities must be maintained until properly relieved in accordance with the station emergency plan requirements. The SM acts as the conduit between station management and the on-shift plant staff. The SM holds an NRC SRO license.

Control Room Supervisor (CRS) – Command and control of the MCR resides with the control room supervisor. The CRS is responsible for all units and directs and oversees the activities of the licensed and non-licensed operators. The CRS is also responsible for authorizing activities that impact plant operations. The CRS is responsible for ensuring the appropriate staff is available in the MCR to manage the available workload. The CRS has the authority to shut down units that are presenting an undue burden to the crew as a tool to manage workload. The CRS always has the authority to direct resources or activities associated with operation of the plant. The CRS maintains and enforces the standards of conduct in the MCR. The CRS holds an NRC SRO license.

Shift Technical Advisor (STA) – The STA provides an objective oversight role for the MCR crew. The STA provides additional on-shift technical support and knowledge to the SM and CRS in the areas of operational event evaluation and accident assessment. The primary duties of the STA include providing technical and engineering advice in assuring safe operation of the plant. This is to be accomplished through additional reviews and evaluations of operating events and accident and incident assessments. The duties of the STA include the review and evaluation of off-normal events. The STA also provides advice or recommendations to the shift on the safety significance and reportability of events as they occur. The STA holds an NRC SRO license.

Reactor Operators (ROs) – Three licensed ROs complete the MCR shift complement. ROs hold NRC RO licenses.

Reactor Operator 1 (RO1) – {{

}}2(a),(c)

Reactor Operator 2 and 3 – {{

}}2(a),(c)

Non-Licensed Operators (NLOs) – NLOs are dispatched from the MCR and Work Control Center and work throughout the plant. NLOs are responsible for operation outside of the MCR including system line-ups, tagging, and investigation as directed by the MCR staff.

2.2.2 Qualifications

For the following positions programs are developed, established, implemented, and maintained using a systematic approach to training (SAT) as defined by 10 CFR 55.4 and ANSI/ANS-3.1-1993, as endorsed by Regulatory Guide-1.8:

- Reactor Operator
- Senior Reactor Operator
- Shift Manager
- Shift Technical Advisor

Qualifications for these positions are discussed in the Staffing and Qualification Results Summary Report (Reference 4.2.7).

2.2.3 Training

Training programs incorporate instructional requirements to qualify personnel to operate and maintain the facility in a safe manner in all modes of operation to protect the health and safety of the public. The programs are developed and maintained in compliance with the facility license and applicable regulations. The training programs are periodically evaluated and revised to reflect industry experience and to incorporate changes to the facility, procedures, regulations, and quality assurance requirements, and are periodically reviewed by management for effectiveness. These training programs are described in site and/or corporate procedures, as appropriate. Sufficient records are maintained and kept available for NRC and accreditation organizations inspection to verify adequacy of the programs.

2.3 Operator Roles and Responsibilities

MCR licensed operators and operating crews outside the MCR are responsible for safe operation and power production. To achieve these objectives, the operators perform a variety of activities:

- structures, systems, or components (SSC) performance monitoring
- local and remote SSC operation
- commanding automated sequences
- directing subordinate operators to perform activities
- monitoring the performance of sequences and procedures
- interrupting and reprioritizing sequences or procedures
- monitoring and evaluating technical specification conditions
- surveillance testing
- reviewing trends
- responding to off-normal conditions
- responding to notifications
- establishing plant conditions to support preventative or corrective maintenance
- maneuvering the plant to support load demand
- summoning additional resources to expand capabilities

Operators are guided and directed in the performance of these activities by regulations, procedures, guidelines, training, and experience. NuScale’s conduct of operations document provides detailed guidance for operation of plant equipment and associated tasks.

2.3.1 Direct Component Operation

When plant and unit SSC conditions permit, operators utilizing procedures can directly operate components in the field, operate components remotely from the MCR, and direct automation to perform steps, sub-steps, and sequences to support operation. As more systems and processes are placed into service, operation transitions from a component and system emphasis towards integrated operation.

Automation Interface – Operators interface with automated functions via a visual display unit (VDU) in most aspects of operation (References 4.2.5 and 4.2.6). Operators employ automation to place equipment into and out of service, conduct tests, and control processes. The specific intent of functional and operability testing is to demonstrate that SSCs and automation perform properly. On successful completion of testing, the integrated SSCs and associated automation remain in (or available for) service during day-to-day operation of the plant. While the SSCs remain in service, operators interact and respond to notifications and recommended sequences.

Operators either directly monitor automation while performing a sequence or rely on limits incorporated within the automation. As illustrated in Figure 2-1, process variables are bounded by automatic control limits and may be bounded by more restrictive operator adjustable limits. If a process parameter reaches an operator-adjustable limit, depending on the automatic control and the operator’s instruction, the sequence may terminate, pause, or alert the operator to the condition. If a process parameter reaches an automatic control limit, a notification is generated and, depending on the nature of the process, other remedial automatic sequences may be initiated.

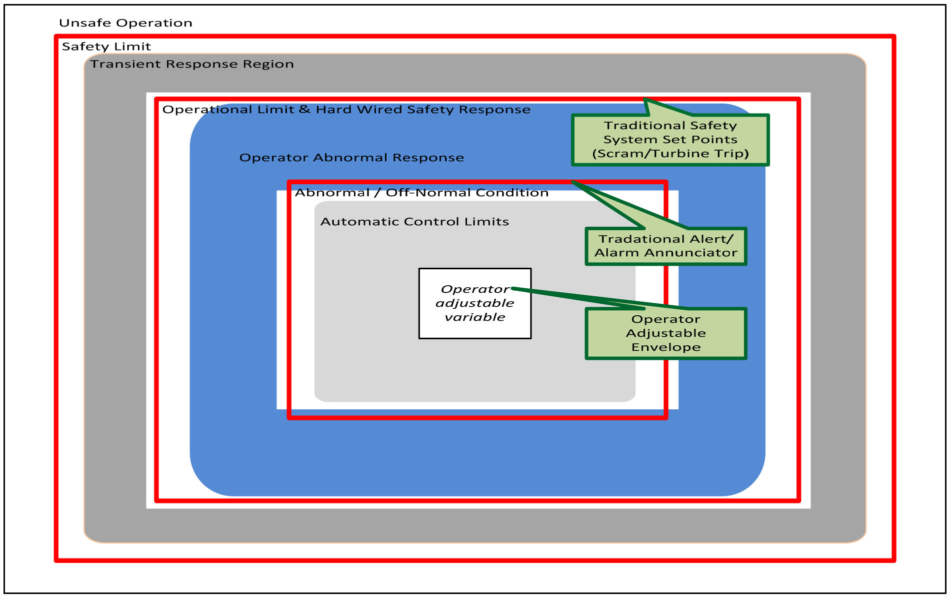

Figure 2-1. Safety and operating limits

2.3.2 Operations Crew Interaction

The operations crew members interact with each other as necessary to accomplish assigned and emergent tasks. Operators communicate with teammates to share information, confirm receipt, recommend actions, and give direction.

While working as members of an integrated multi-unit team, operators perform differing tasks. Consequently, each operator on the team has unique situational information. An operator performing tasks on a specific unit will typically respond to off-normal conditions on that unit depending on the nature and severity of the condition. The CRS will ensure the appropriate operator responds based on the current resource loading.

When basic information may be passed to a single teammate, communications are conducted in a non-distracting fashion. For example, if a teammate neglected to document a completed task, another operator may prompt the teammate to correct the oversight. When urgent information must be passed to multiple teammates, operators make announcements to the crew.

Operators interface with other licensed and non-licensed members of the plant organization. This interaction can include support for maintenance activities, performance of surveillance activities, planning, tagging, training, troubleshooting of issues, request for support of plant issues from plant organizations (e.g., chemistry, engineering, health physics) and other activities.

2.3.3 Document Review

Operators access the information and record management system to review technical documents, reports, test results, and other work documents to confirm the readiness of unit and plant SSCs.

2.4 Machine Agent and Shared Roles

There are differing levels of automation, from fully automated to manual assist. Human interaction or monitoring is necessary when automation is used to perform a task. Human interaction with automation can include setting control parameters, initiating actions, securing automation, and manual adjustments of automated processes. Within the HFE program function allocation process (Reference 4.2.3), functions and their derivate tasks are allocated to a level of automation. The level of automation directly influences the digital HSI automation the operator uses to execute tasks.

Inherent in the automation's support role is providing the supporting basis for all recommendations, thereby facilitating the operator's evaluation of the recommendation given the operator's knowledge of upcoming activities.

2.4.1 High Cognitive Burden Functions

NuScale employs automation to facilitate continuous monitoring, plant maneuvering, and perform repetitive tasks.

Key parameter monitoring is supported by intuitive HSI display of values and recent historical trends. Key safety function parameters are automatically evaluated and displayed in simple color coded displays to allow operators to prioritize and manage workload.

2.4.2 Continuous Monitoring

NuScale relies on automation to control basic intermittent and continuous processes (such as hot well level control or turbine speed control) and provide continuous process parameter notification monitoring. The advantage of the digital NuScale MCR and higher levels of automation is to provide operators displays with expanded monitoring capabilities.

A key HSI feature associated with automated operation is to enable performance monitoring by operators. The HSI enables operators to manage automation by providing necessary information, displays and controls to enable observation, independent verification and operator intervention (Reference 4.2.5). For example, if automation is monitoring or controlling a parameter, operators have access to observe the set points for action and consequential actions should the set point be reached. As illustrated in Figure 2-1, if the set point allows for operator adjustment, the operator may intervene and adjust appropriate set points within allowable limits.

2.4.3 Parameter Monitoring

Automation performs functions associated with parameter and process monitoring, including defined sequence functions, continuous process control, notifications monitoring, safety function monitoring, and automatic safety actuations. Operators monitor and evaluate automated functions, intervening as required. Operators also elect to share control with the automation or assume control of the automated function.

Generally, operators observe process parameters being monitored by automation. This shared role of process monitoring supports situational awareness and enables the operator to evaluate automated system performance. Operators increase attention to performance monitoring when:

- transients are anticipated
- sustained normal automated operation needs to be confirmed
- degraded automation is suspected

Operator Intervention – Operators intervene when it becomes apparent that the automation has failed or when the automation is no longer appropriate for the current or planned plant conditions.

2.4.4 Repetitive Tasks

Repetitive tasks are those that involve multiple identical component manipulations. Repetitive tasks can be error-likely tasks for operators, making these tasks more appropriately assigned to automation. This type of automation typically has no auto-initiation capability and must be initiated by an operator. Provided the prerequisite conditions are satisfied, the sequence proceeds to perform the repetitive task, logging each action while continuously monitoring key parameters. In the event of a malfunction, the HSI alerts the operator of the condition and logs the event. On successful completion of the task, the automation alerts the operator of the successful completion and logs the event. During the HFE function allocation and task analysis process, operator tasks, including those identified as repetitive tasks, are allocated to a level of automation that allows operators to interact (initiate and monitor) with various tasks (Reference 4.2.3, 4.2.5, and 4.2.6).

2.4.5 Startup and Shutdown

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}}[2(a),(c)]

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}}2(a),(c)

2.4.6 Power Maneuvering

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}}2(a),(c)

2.4.7 Primary System Process Control

Key reactor coolant parameters are continuously monitored by automation. When one of these parameters approaches an administrative limit, the automation responds. Depending on the parameter, the associated automation may respond with or without operator involvement.

Reactor pressure control at normal operating pressure is an example of primary system process control without operator involvement. As described above, under continuous monitoring operators may elect to monitor the pressure controlling automation performance at any time. The automation controlling pressure does so without direct operator involvement. The operator is able to take manual control, such as for drawing or collapsing the pressurizer steam bubble or changing the control pressure during automatic operation.

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}}2(a),(c),ECI

2.4.8 Other Automation

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}}2(a),(c)

2.5 Communications Techniques and Equipment

2.5.1 Face-to-Face Communications

When verbal information that is directive in nature is exchanged between people via face-to-face, telephone, radio, or other means regarding one or more of the following:

- status of plant systems, structures, or components
- direction to perform action(s) on plant equipment action
- work instructions, limitations and cautions

Three-way communication is used to provide the formality and structure to minimize communication errors.

2.5.2 Control Room Update Announcement

Control room crew announcements are made to maintain crew situational awareness. When urgent information must be passed to multiple teammates, operators will make announcements to the crew.

2.5.3 Phone and Radio Communications

For direct communication with operators outside of the MCR, phone, radio, or other communication is used.

2.5.4 Public Address

The public address system is used to communicate important information and should be used judiciously. It is expected that all personnel on site stop and listen to public address announcements. General paging is not done via the public address system. When public announcement transmissions are warranted, they are as concise as possible, using standard phraseology for the site, and spoken in a clear, slow and emotion-neutral tone.

3.0 Overview of the Human-System Interface and Supporting Equipment

3.1 Facility Layout

The NuScale MCR contains the following equipment and features (see Figure 3-1):

- a bank of VDUs configured with safety display and indication system HSIs
- sit-down work stations for three reactor operators, each able to access HSIs for all units and common systems
- sit-down work stations for three senior reactor operators (SM, STA, and CRS)
- a dedicated stand-up control panel for each unit
- a dedicated stand-up control station for shared or common systems
- dedicated manual controls for safety system actuation, component repositioning, and overriding of specific safety signals in severe accident conditions.

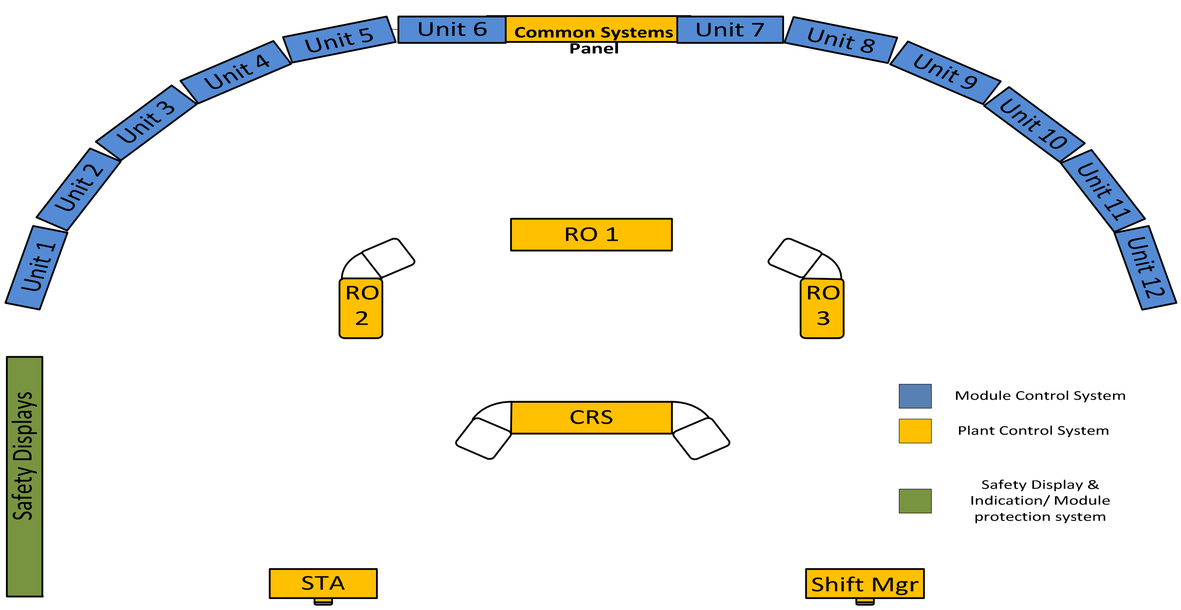

Figure 3-1. NuScale main control room layout example

3.2 Workstations, Displays, and Working Positions

3.2.1 Safety Display and Indication System Display Panels

The safety display and indication system VDUs provide redundant, highly reliable indications of unit conditions. Operators rely on these indications to give them the status of the plant, even in conditions where normal power and backup power have been lost for an extended period of time. The safety display and indication system VDUs used to provide plant safety information to the crew use unique interface coding to display the information (display pages) to the crew. The safety display and indication system (SDI) receives input only from the module protection system (MPS) and plant protection system (PPS) and processes it through redundant communication hubs for display. The communication hubs send information to the safety display screens in the control room. The redundant nature of the design prevents a single failure from preventing information display to reach the operator. This information is used by operators to assess current plant conditions and the status of actuation devices controlled by either the MPS or PPS. The SDI is equipped with redundant 72 hour battery back-up to continue to provide indications when all AC power is lost. All communications to and from the SDI are carried on fiber optic communication lines to protect against hot shorts.

3.2.2 Sit-Down Operator Workstations

Each of the operator workstations shown in Figure 3-1 includes four VDUs as depicted in Figure 3-2. It is understood that display technology changes and the function of the four VDUs may be accomplished by other means; for example, a single monitor that can be divided into the same functional displays. The HSIs displayed on the VDUs are navigable and contain the alarms, controls, indications, and procedures necessary to monitor and manage any unit chosen by the operator during normal, abnormal, emergency, shutdown, and refueling operations.

The MCR operators and supervisors interface with the plant at their designated workstations using HSI software located on the plant control system (PCS) and MCS networks. Due to high levels of automation and passive safety functions, multiple units may be controlled by a single operator at any workstation simultaneously. Additionally, common or shared plant systems are able to be fully monitored and managed from each workstation. The capability of the HSI and the supporting PCS and MCS network architecture structure allows the operator workstations to support oversight and control activities.

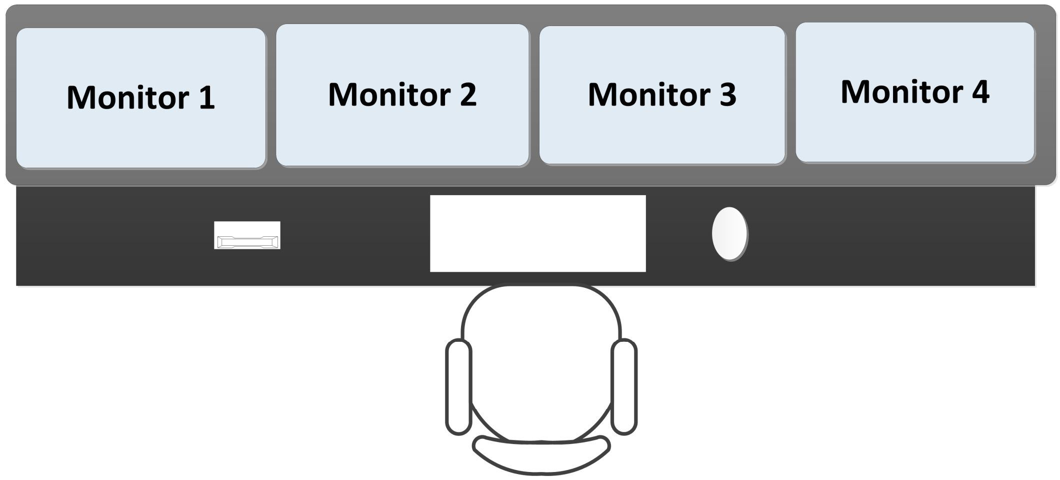

Figure 3-2. Sit-down operator workstation

3.2.3 Stand-Up Unit Workstations

Figure 3-1 shows twelve unit workstations. Each unit workstation is a stand-up workstation with five VDUs, a keyboard, a mouse, and “manual” switch backups for protective functions.

The unit workstation is depicted in Figure 3-3.

The HSIs displayed on the four unit VDUs are navigable and contain the alarms, controls, indications, and procedures necessary to monitor and manage that particular unit during normal, abnormal, emergency, shutdown, and refueling operations. Similar to the sit-down operator workstations, the function of the five VDUs may be accomplished by other means; for example, a single monitor that can be divided into the same functional displays.

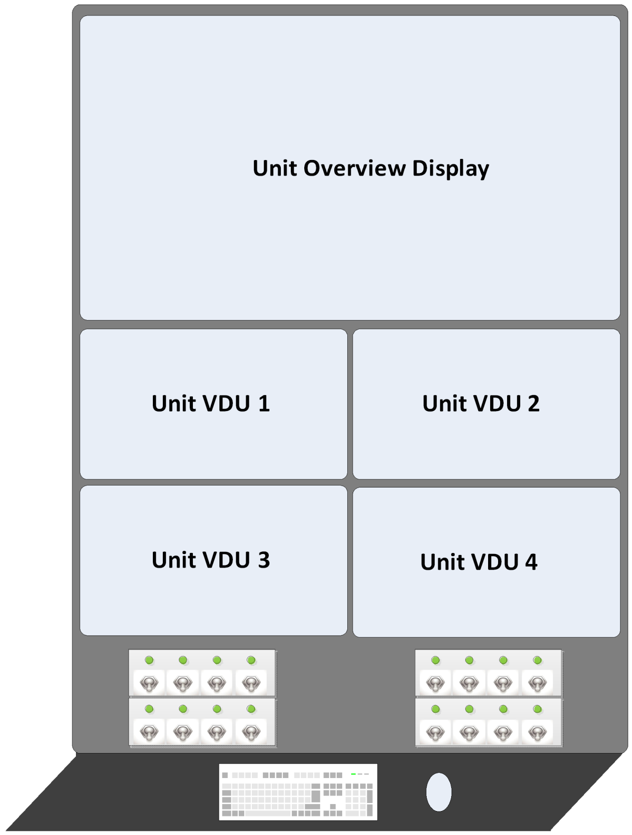

Figure 3-3. A stand-up unit workstation

During most operating conditions, the uppermost larger unit workstation VDU (i.e., unit overview display) provides an overview display for that unit so that other MCR personnel can quickly determine status.

The synchronized data control capabilities of the unit control system allow an RO to perform more dedicated specific-unit activities on each of the 12 unit stand-up unit workstations. The stand-up unit workstations are specific to each unit (e.g., only unit 3's components can be operated from unit workstation 3).

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}}2(a),(c)

3.2.4 Stand-Up Common Systems Panel

The common systems panel, illustrated in Figure 3-4, includes VDUs that provide HSIs for alarms, controls, indications, and procedures for systems common to all 12 NuScale units (e.g., reactor pool cooling, instrument air, reactor building and radwaste building ventilation, radioactive waste systems). The common systems stand-up panel can only access and control components that are common for more than one unit.

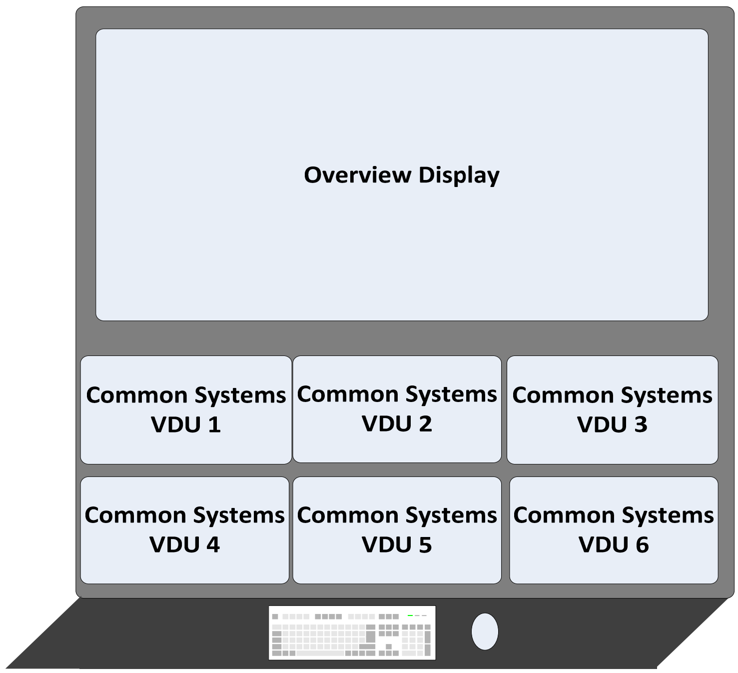

Figure 3-4. Common systems panel

The overview display is a NuScale plant-wide overview with specifically selected plant-wide monitoring items visible to any operator in the MCR. Similar to the stand-up unit workstations, the function of the VDUs may be accomplished by other means.

3.2.5 Arrangement of Human-System Interfaces

The HSI layout in the MCR is specifically designed to support minimum, nominal, and enhanced staffing during all operating plant modes. Shared system VDUs and unit/plant overview VDUs are located such that they can be observed from multiple locations within the MCR. Unit workstations are spaced so that side-by-side operation at adjoining units allows sufficient room to maneuver.

Local Control Stations – Provided to facilitate subsystem startup, shutdown, refueling activities, maintenance, post maintenance testing, or operational flexibility.

Other Stations – Includes such stations as the remote shutdown station, technical support center, operations support center, and emergency operations facility. This also may include alternate unit work stations located within or outside of the main control room to support potentially complex operations and maintenance activities that supplemental staff would perform.

3.2.6 Work Control Center

The Work Control Center supports operations and maintenance by providing a location outside of the main control room for administrative tasks associated with day to day activities.

3.3 Human-System Interface Design Features

3.3.1 Features that Support Operating Crew Size

As shown in Figure 3-1, the concave MCR layout provides the operators a panoramic view of each of the unit overview displays and the common systems overview display. Unit and plant overview displays provide different information in a way that supports intuitive access to unit, common, and integrated plant status. The proximity of the sit-down operator workstations promotes cooperation and communication while the viewing angle from the sit-down workstations to the stand-up unit workstations allows operators to direct the focus of others.

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}}2(a),(c)

3.3.2 Features that Support Human Performance

As described in references 4.2.5 and 4.2.6, consistent workstation and individual screen layout design aspects such as text size, use of color, icon development, general information arrangement, navigational requirements, notification placement, and the use of animation support operator awareness and provide a predictably intuitive interface. This consistency ensures that operators are able to quickly orient themselves regardless of the unit or system they are interfacing. Required indications for each system are displayed in a consistent manner that also provides an overview of expected values and ranges for those indications.

The NuScale plant notification system aids operator understanding of plant status and enhances the ability to make a judgment based on experience and skill.

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3.3.3 Features That Consider Environmental Conditions

As described in references 4.2.5 and 4.2.6, consistent workspace design aspects related to ergonomics and environment (e.g., height, viewing distance, reach, lighting, temperature, humidity) support operator comfort in order to limit distractions and minimize fatigue. The standards developed in reference 4.2.5 are applicable to HSIs throughout the plant and include standards for design features such as the overall layout of the workstations and other equipment such as group-view displays within the workplace, but also considers support equipment such as ladders or tools, and environmental characteristics including temperature, ventilation, illumination, and noise.

3.3.4 Features That Support Situational Awareness

Situational awareness is supported by features that also support human performance, such as consistent workstation and individual screen layout and the plant notification system design.

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The majority of plant logs are recorded automatically and allow Operations to search or filter historic data to identify trends that indicate developing issues or to troubleshoot.

3.3.5 Other Features

Communications between the MCR and outside the MCR is normally by secure telephone or radio. Normal incoming and outgoing calls are made by reactor operators and senior reactor operators not “at-the-controls.” MCR telephones are portable, allowing the operators freedom of movement during communications. Depending on the nature and urgency of the communication, operators may communicate using the public address system, secure cell phones, pagers, text messages, or e-mail, as appropriate.

3.4 Interaction with Human-System Interface during Normal Operations

During routine operations, the MCR staff monitors and controls both operating and shutdown units that are the responsibility of the control room (once a module is disconnected in preparation for refueling it is the responsibility of the refueling SRO). Units are monitored and controlled to ensure safe operation. Scheduled plant or unit evolutions can be supported by additional staffing such that the normal MCR staff is not overloaded. The additional manpower, if needed, enables the crew to appropriately focus on monitoring and control of the remaining units while the augmented staff attends to the designated evolutions.

3.4.1 Tasks Performed during Normal Operations

Automated Parameter and Condition Monitoring – Automation is assigned to continuously monitor, display, record, and communicate all identified unit, common, process, and computed parameters or values as appropriate. Automation monitors various limits, variables, and administrative inputs providing appropriate notification and process control adjustments as required.

Automated Tasks and Evolutions – Automation, when directed by an operator or prompted by an automated process, generates reports on component, subsystem, or system status and configuration. Reports typically address post-maintenance testing, system lineup, operational readiness, periodic maintenance, identified deficiencies, lockouts, temporary set points, and operational history.

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Automated Plant Power Maneuvering – Automation continuously monitors key process parameters (main turbine, steam generator, steam, feedwater, and reactor coolant system temperatures and flows, components, and controls) enabling operators to control and adjust power. Operators select a desired power and electric load target, then direct automation to maneuver the unit and subordinate automation to bring the unit from its current power level to the target level.

Automated Testing – Automation, when directed by an operator and when prerequisite conditions are satisfied, manipulates the subsystem, system, or process controls to establish test conditions. {{

}}2(a),(c) On satisfactory test completion, a report is generated to document and record test results. At any point in the test or activity, if test results are marginal or unsatisfactory, the automation alerts the operator of the problem and places the component, subsystem, or system in a pre-set and appropriate configuration for the unconfirmed degraded condition while operators evaluate the issue. Depending on the nature of the problem, the test may be completed, partially completed, or aborted and the component, subsystem, or system designated as operable, nonconforming, degraded, or inoperable. When the test is terminated, a test report is generated that documents the test, the results, and the immediate remedial actions, where applicable.

Procedures – Normal operating procedures are provided to guide operators during startup, shutdown, and steady state power operations. {{

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3.5 Interaction with Human-System Interface during Off-Normal, and Emergency Operations

3.5.1 Off-Normal and Emergency Functions

Parameter and Process Monitoring – In addition to those tasks required for normal operations, automation continuously monitors operational limits, automation limits, and operator adjustable variables. When pre-defined conditions are detected, automatically generated notifications, process parameters adjustments, and safety functions are initiated.

Abnormal and off-normal conditions are detected by automated monitoring of plant and unit conditions. When a condition is detected outside operational limits, automation notifies the operator of the abnormal or off-normal condition. Notifications allow the operator to intervene and return conditions within limits using operator actions and/or other automation.

Operational Limits – define the boundary where automatic controls and off-normal conditions have been exceeded and the operator expected response has been unsuccessful in restoring normal operation. In degraded conditions, automation generates notifications and/or triggers safety functions. Safety functions are discrete actions to place systems and subsystems in a safe condition. Safety functions initiate discrete systems, such as reactor scram, containment isolation, decay heat removal, or emergency core cooling, and do not control processes nor do they modulate to control conditions or parameters.

In parallel with actions by automation, when predetermined protection limits have been exceeded, operators initiate emergency procedures as appropriate. Emergency procedures direct operator and supervisory actions. The operator (RO1, RO2, and RO3) actions stabilize the plant. The supervisory (CRS, STA, and SM) actions support and direct the operations staff, marshal additional plant manpower, and inform designated regulatory and government bodies of the emergency.

3.5.2 Procedures for Off-Normal Operations

Transition from Normal to Off-Normal Operations – Operators monitor automation to detect the transition from normal to off-normal operations. When process parameters, automation sequences, or plant conditions depart from normal conditions, the plant notification system alerts the operator to an off-normal condition. In most situations, off-normal conditions are a result of component, system, or automation malfunctions. The nature and extent of the conditions are seldom fully understood at the onset of the event and the operating crew objective is to safely stabilize the unit and investigate the condition with the goal of safely restoring the unit to normal operation.

If the operator's judgment is that continued operation of an automated process would be adverse to safe operation of the plant, then the operator may assume control of the automation. If possible, the operator obtains CRS permission beforehand.

When an off-normal condition is detected, depending on the condition, other automatic processes take preset action to stabilize the system and/or unit. Operators verify that the automation has properly identified off-normal conditions and is taking or has completed the required action.

<u>Event Based Off-Normal Procedures</u> – Off-normal procedures are approved directions operators follow in response to a specific event. The directions provide planned and approved operator preventive or remedial actions to stabilize conditions. These actions may duplicate or expand upon functions performed by automation.

Off-normal procedures are integrated with the alarm response procedures. The majority of upset conditions are either restored or recovered by automation or result in a unit shutdown. An operating NuScale unit has a limited number of active components so off-normal conditions are likely to have either straightforward resolutions or require a plant shutdown to address.

Computer-based procedures facilitate mobility and operator use. Paper-based procedures are available as backups in the event of computer difficulties. Examples of event based off-normal procedures include

- turbine trip
- fire
- loss of AC or DC electric bus
- high winds/tornado
- flooding

<u>Symptom-Based Emergency Procedures</u> – Emergency procedures are approved directions operators perform in direct response to specific entry conditions associated with off-normal conditions. Emergency procedures take priority with respect to resource allocation and urgency. Emergency procedures provide planned and approved operator actions in response to specific plant symptoms (conditions, process parameters, or indications) to stabilize conditions and protect the health and safety of the public.

Examples of off-normal conditions leading to emergency procedures include

- reactor building high radiation
- anticipated transient without scram (ATWS)
- loss of coolant accident

Emergency procedures and post-trip safety function displays direct operator response to restore and maintain important control functions. Examples of important control functions the procedures address include

- reactivity control
- inventory control
- containment isolation

The NuScale plant and safety system design is simplistic with respect to emergency responses so emergency procedures are not complex. Most emergency responses involve ensuring that plant response is within the expected performance envelope and taking actions when necessary to ensure that the limits of that envelope are not threatened.

3.6 Interaction with Human-System Interface during Maintenance and Modifications

3.6.1 Operator Tasks Supporting Maintenance

Work documents are prepared by the maintenance organization to identify prerequisite conditions (de-energize, depressurize, and lockout), the scope of work, and post-maintenance testing. Maintenance personnel have access to work documents and procedures in an electronic format on a device such as a tablet.

Operators review maintenance work documents to identify necessary changes to plant and unit configurations and the regulatory impact of removing equipment from service. Based on the review, a work boundary is established and boundary components (valves, blind flanges, vents, drains, circuit breakers, fuses) are identified to separate workers from hazards. {{

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Operators facilitate maintenance lockout of equipment to ensure maintenance lockouts are applied to the proper equipment. When lockouts are established and checks completed to verify safe working conditions, the maintenance activities are performed. On completion of the work, lockouts are removed and the systems are reconfigured for post-maintenance testing.

3.6.2 Automated Tasks Supporting Maintenance

Boundary components identified and established by operators to protect maintenance personnel from hazards are recorded in a database.

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3.6.3 Human-System Interfaces and Procedures for Maintenance

Maintenance activities seldom require active component manipulation. When such manipulation is required, evolutions are conducted using normal procedures. For example, when a valve stem must be stroked to adjust packing, lockouts will be removed and maintenance personnel coordinate with Operations to stroke the valve. When the necessary manipulations are complete, the necessary lockouts are restored.

3.6.4 Human-System Interfaces and Procedures for Modifications

Modifications are managed as a maintenance activity. Depending on the scope and nature of the modification, the activities may be inconsequential or significant. For example, modifying automation unique to a particular and infrequent activity may be implemented and tested during power operations. Conversely, modification to automation that controls a critical process requires extensive testing prior to implementation. At the time of implementation, the plant or unit may require reconfiguration to a safe condition where malfunction of the modified automation can do no harm. After post-modification testing, the reconfiguration for normal operations occurs.

4.0 References

4.1 Source Documents

4.1.1 U.S. Code of Federal Regulations, “Domestic Licensing of Production and Utilization Facilities,” Part 50, Chapter 1, Title 10, “Energy,” (10 CFR 50).

4.1.2 *U.S. Code of Federal Regulations*, “Operators’ Licenses,” Part 55, Chapter 1, Title 10, “Energy,” (10 CFR 55).

4.1.3 International Atomic Energy Agency (IAEA), “Conduct of Operations at Nuclear Power Plants,” Safety Guide NS-G-2.14, 2008.

4.1.4 U.S. Nuclear Regulatory Commission, “Human-System Interface Design Review Guidelines,” NUREG-0700, Rev. 2.

4.1.5 U.S. Nuclear Regulatory Commission, “Guidance for Assessing Exemption Requests from the Nuclear Power Plant Licensed Operator Staffing Requirements Specified in 10 CFR 50.54(m),” NUREG-1791.

4.1.6 U.S. Nuclear Regulatory Commission, “Human Performance Issues Related to the Design and Operation of Small Modular Reactors,” NUREG/CR-7126.

4.1.7 Human Factors Aspects of Operating Small Reactors. O’Hara & Higgins, 2010. BNL-93943-2010-CP.

4.1.8 Draft Function Allocation Framework and Preliminary Technical Basis for Advanced SMR Concept of Operations, INL/BNL -13-28601/TR-2013/02, Rev 1.

4.2 Referenced Documents

4.2.1 Owners Requirements Document, OP-0000-1500.

4.2.2 Human Factors Engineering Program Management Plan, RP-0914-8534.

4.2.3 Human Factors Engineering Functional Requirements Analysis and Function Allocation Results Summary Report, RP-0316-17615.

4.2.4 U.S. Nuclear Regulatory Commission, “Human Factors Engineering Program Review Model,” NUREG-0711, Rev. 3, November 2012.

4.2.5 Human System Interface Style Guide, ES-0304-1381

4.2.6 Human System Interface Design Results Summary Report, RP-0316-17619.

4.2.7 Human Factors Engineering Staffing and Qualifications Analysis Results Summary Report, RP-0316-17617.

Enclosure 7:

Human Factors Engineering Design Implementation Implementation Plan, RP-0914-8544-NP, Revision 1, non-proprietary version

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Human Factors Engineering Design Implementation Implementation Plan

September 16, 2016

Revision 1

Docket: PROJ0769

NuScale Nonproprietary

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CONTENTS

Abstract

NUREG-0711 provides guidance for the development of methodologies to address the elements of the human factors engineering program. Design implementation is an element of the HFE program that verifies conformance of the as-built design to the planned design. The Design Implementation element is complete after the plant construction is complete.

This implementation plan describes the methodology for conducting the design implementation element. The methodology is consistent with the applicable provisions of Section 12 of NUREG-0711, Revision 3.

Executive Summary

The methodology for design implementation ensures that the as-built design of the NuScale Power plant accurately reflects the verified and validated design resulting from the human factors engineering design process. Design implementation activities include evaluation of those aspects of the design that were not addressed during human factors verification and validation. The methods used to verify that the final human-system interfaces, facility configuration, procedures, and training program conform to the planned design including configuration control, HFE review, plant walkdowns, and review of potential design changes. The HFE issues identified during these activities are documented, evaluated, and tracked as human engineering discrepancies within the HFE issues tracking system. Conformance of the as-built design to the planned design is assured by an inspections, tests, analysis, and acceptance criteria item that tracks the design implementation activities. Any changes to the human-system interfaces following fuel load are addressed by the holder of a combined license.

1.0 Introduction

1.1 Purpose

This document provides the implementation plan (IP) for design implementation (DI) within the NuScale plant human factors engineering (HFE) program. DI demonstrates that the HFE program "as-built" design of human-system interface (HSI), facility configuration, procedures, and training program accurately reflects the verified and validated design resulting from the HFE design process. DI activities also include evaluation of those aspects of the design that were not addressed during human factors verification and validation (V&V).

Features evaluated during DI generally include those that cannot be accurately simulated:

- ergonomic considerations such as lighting and background noise
- HSIs outside of the main control room (MCR) but within the NuScale plant HFE program scope

Human engineering discrepancies (HEDs) generated during V&V that do not have any impact on plant safety or plant performance and operability, but are determined to require resolution, are resolved during DI. The HEDs that are generated after completion of V&V that are determined to require resolution are also resolved during DI. Resolution of the HEDs is in accordance with the process described in the HFE Program Management Plan (Reference 8.2.1).

Any reevaluation or HFE program activity iterations that are needed after V&V are conducted and documented during DI. The DI element of the HFE program is complete after the plant construction is complete. Any changes to the HSI following fuel load are addressed by the combined license holder.

Completion of DI activities is tracked and confirmed by an inspections, tests, analysis, and acceptance criteria (ITAAC) item. This ensures that the as-built design conforms to the verified and validated design resulting from the HFE design process. Therefore, a results summary report (RSR) is not prepared for the DI element of the HFE program as part of design certification.

1.2 Scope

For the MCR and each local control station (LCS), the DI element confirms that

- the facility configuration of the as-built design matches the aspects of the facility that were simulated during the integrated system validation (ISV).
- other aspects of the facility that were not simulated but are relevant to the overall HFE program are evaluated using an appropriate V&V method.

The HSIs, procedures, and training program evaluated for conformance apply to the MCR and certain LCSs during normal, abnormal, and emergency operating conditions. This IP does not apply to maintenance or refueling activities, activities completed by craft/technical personnel (i.e., mechanical, electrical, or instrumentation and control (I&C), health physics, chemistry, engineering, or information technology), or activities associated with the remote shutdown station (RSS), the technical support center (TSC), emergency operations facility (EOF), operations support center (OSC), or any other emergency response facilities unless they are determined to impact licensed operator responsibilities (see Reference 8.2.1).

1.3 Abbreviations and Definitions

Table 1-1. Abbreviations

Term	**Definition**
DI	design implementation
HED	human engineering discrepancy
HFE	human factors engineering
HFEITS	human factors engineering issue tracking system
HPM	human performance monitoring
HSI	human-system interface
IHA	important human action
IP	implementation plan
ISV	integrated system validation
ITAAC	Inspections, tests, analysis, and acceptance criteria
LCS	local control station
MCR	main control room
RSR	results summary report
RSS	remote shutdown station
SME	subject matter expert
TSC	technical support center
V&V	verification and validation

2.0 Design Implementation Assessments

Design implementation uses the following methods to verify that the final HSIs, facility configuration, procedures, and training program conform to the planned design that resulted from the HFE design process and V&V activities:

- configuration control
- HFE review
- plant walkdowns
- review of design changes

The DI assessments for software, hardware, and facility configurations confirm clear configuration-controlled design traceability for HSI components (alarms, controls, indications, and procedures) and peripheral equipment. The as-built configuration is compared to the drawings, specifications, and other final design documents used for ISV to determine conformance. If the as-built configuration is not confirmed to be in conformance with these design documents, further HFE review is conducted to determine if the as-built HSI is equivalent to the HSI of the ISV.

The DI assessment for facility configuration is conducted by plant walkdown and includes

- physical configuration of workstations, panels, and displays
- visibility and sight lines
- accommodations for communication
- inclusion of emergency plan and personal protection equipment
- lighting
- background noise
- environmental controls/conditions (e.g., temperature and humidity)

The evaluation of aspects of the facility not simulated (e.g., LCSs) but relevant to the overall HFE program include

- a walkdown to confirm conformance to the documentation approved by the HFE team and that these components do not challenge conclusions of the V&V.
- a subject-matter expert (SME) review of
  - the suitability of the LCS for executing the operating procedures where operating procedures direct use of that LCS (i.e., typically not computer-based procedures).
  - the suitability of those procedures.

- an SME evaluation of training material used for the MCR and LCS HSIs to ensure it comprehensively includes the material provided to operators who participated in the ISV.

Where configuration-controlled design traceability, HFE review for HSI equivalency to the HSI of the ISV, and/or plant walkdown do not confirm that the as-built HSIs, procedures, and training program design is the planned design, an HED is generated. If an HED evaluation determines that a design change would potentially resolve the HED, a design change review is conducted to determine the significance of the differences between planned and as-built. If the design change review concludes that the design change has no impact on the completed ISV, then a specific validation method (e.g., tabletop walkthrough, mockup, part-task simulator, or plant walkdown) is determined. If the ISV results are impacted by the design changes, the applicable portion(s) of ISV are repeated.

The design change review also determines the need to reiterate or repeat other elements or activities of the HFE program and the extent of this rework.

3.0 Human Factors Engineering Issues Tracking System Resolution

HFE issues found during the DI activities described in Section 2.0 are documented, evaluated, and tracked as HEDs within the HFE issues tracking system (HFEITS) (see Reference 8.2.1). As described in the human factors V&V IP (Reference 8.2.2), HEDs from earlier HFE program elements and those generated during V&V activities are closed prior to ISV. HEDs generated during V&V that do not affect plant safety or plant performance and operability, but determined to require resolution, and HEDs generated after completion of V&V that are determined to require resolution are *resolved* during DI. Some HEDs may not be resolved during HFE program activities and may be on-going due to anticipated technology or other advancements; however, all HEDs are *closed* prior to DI completion.

4.0 Addressing Important Human Actions

Important human actions (IHA) are determined, addressed, and tracked by the Treatment of Important Human Actions element of the HFE program. The IHAs are incorporated into the HSI (alarms, controls, indications, and procedures) design.

As described in the human factors V&V IP (Reference 8.2.2), IHAs are considered among the significant conditions, personnel tasks, and situational factors sampled during V&V activities as the ISV scenarios are developed. The ISV assesses the successful performance of the integrated crew and the HSI for IHAs. During V&V, HEDs are processed when discrepancies are found for any IHA. HEDs found during V&V are resolved during DI as described in Section 3.0.

5.0 Additional Considerations for Human Factors Engineering Aspects of Control Room Modifications

After completion of start-up testing and provisional turn over, a licensee institutes a human performance monitoring (HPM) program to evaluate impacts on human performance going forward. The HPM program evaluates design change proposals for HSI design, procedures, or training against the design bases established for the as-built design. The design change proposal evaluation considers HEDs in HFEITS regardless of which stage of the design in which they were initiated. HFE program activity results that are invalidated by design changes are reconducted to support plant modification without reducing human performance (see Section 2.0).

A licensee's design change process is governed by regulatory requirements such as 10 CFR 50.59, Changes, tests, and experiments (Reference 8.2.3).

6.0 Results Summary Report

Completion of DI activities is tracked and confirmed by an ITAAC item. This ensures that the as-built design conforms to the verified and validated design resulting from the HFE design process. Therefore, an RSR is not prepared for the DI element of the HFE program as part of design certification.

7.0 NUREG-0711 Conformance Evaluation

Table 7-1 indicates where each NUREG-0711, Rev. 3 (Reference 8.2.4) criterion is met in this IP.

Table 7-1. Conformance with NUREG-0711

Review Criteria Stated in NUREG-0711, Rev. 3	DI IP Section No. and paragraph
12.4 Review Criteria 12.4.1 Final HFE Design Verification for New Plants and Control Room Modifications 1. The applicant should evaluate aspects of the design that were not addressed in V&V by an appropriate V&V method. *Additional Information: Aspects of the design addressed by this criterion may include design characteristics, such as new or modified displays for plant-specific design features.*	Section 1.2, all paragraphs Section 2.0, all paragraphs
2. The applicant should compare 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. This verification should compare the actual HSI, procedures, and training materials to design descriptions and documents. Any identified discrepancies should be corrected, or justified. *Additional Information: Final design means the design existing in the actual plant.*	Section 2.0, all paragraphs Section 3.0, all paragraphs
3. The applicant should verify that all HFE-related issues in the issue-tracking system (Section 2.4.4) are adequately addressed.	Section 3.0, all paragraphs
4. The applicant should provide a description of how the HFE program addressed each important HA.	Section 4.0, all paragraphs
12.4.2 Additional Considerations for Reviewing the HFE Aspects of Control Room Modifications In addition to any of the criteria above that are relevant to the modification being reviewed, the following should be addressed. 12.4.2.1 General Criteria for Plant Modifications 1. The applicant should provide reasonable assurance that the reactor fuel is safely monitored during the shutdown period while physical modifications to the control room are being made.	N/A, Section 5.0
2. The applicant should verify that modifications in the plant's procedures and training reflect changes in plant systems, personnel roles and responsibilities, and in HSIs resulting from the new systems.	N/A, Section 5.0
3. Installation should be planned to minimize disruptions to work of plant personnel.	N/A, Section 5.0
4. The applicant should verify that operations and maintenance personnel are fully trained and qualified to operate and maintain all modifications made to the plant before starting up with the new systems and HSIs in place.	N/A, Section 5.0

Review Criteria Stated in NUREG-0711, Rev. 3	DI IP Section No. and paragraph
5. The applicant should have a plan to monitor start-up and initial operations after the modification to reasonably assure that: • operational and maintenance problems arising from personnel's interactions with the new systems, HSIs, and procedures are identified and addressed • personnel are sufficiently familiar with the new systems, HSIs, and procedures to support safe operations and maintenance • any negative transfer of training from the old removed HSIs to the corresponding new ones was identified and corrected • no new problems are created by coordinating tasks between the remaining old HSIs and new HSIs • no unanticipated negative effects on personnel interaction and teamwork have surfaced	N/A, Section 5.0
12.4.2.2 Modernization Programs Consisting of Many Small Modifications 1. The applicant should assure that each modification follows an HFE program that provides standardization and consistency (1) between old and new equipment, and (2) across the new systems being implemented.	N/A, Section 5.0
2. The applicant should verify that new modifications fulfill a clear operational need, and do not interfere with existing systems. *Additional Information: For example, the auditory alerts in a new HSI should not distract operators from addressing more important alarms.*	N/A, Section 5.0
12.4.2.3 Modernization Programs Consisting of Large Modifications during Multiple Outages 1. Interim configurations may exist for long times (e. g., a refueling cycle), and therefore, applicants should verify that they are acceptable from both engineering and operations perspectives and that they meet regulatory requirements. The applicant's evaluations should include: • PRA evaluations to ensure minimizing high-risk situations • FSAR evaluations to assure defense against design basis accidents • technical-specifications evaluations to determine if changes are needed • defense in depth evaluations to ensure meeting the criteria in RG 1.174	N/A, Section 5.0
2. The applicant should perform task analysis for each interim configuration to verify that any task demands are known and do not degrade personnel performance.	N/A, Section 5.0
3. The applicant should update the HRA to address any unique tasks that may impact risk, as well as any changes to existing tasks due to the interim configuration.	N/A, Section 5.0
4. The applicant should verify that the HSIs needed to perform important tasks (as defined in Section 6) are consistent and standardized. Personnel should not have to use both old and new HSIs for different aspects of the same task.	N/A, Section 5.0
5. The applicant should develop procedures for temporary configurations of systems and HSIs that personnel use when the plant is not shutdown.	N/A, Section 5.0
6. The applicant should develop training for temporary configurations of systems, HSIs, and procedures that personnel can use when the plant is not shutdown.	N/A, Section 5.0

Review Criteria Stated in NUREG-0711, Rev. 3	DI IP Section No. and paragraph
7. The applicant should consider the following aspects of V&V: • HFE Design Verification – Temporary configurations of the systems, HSIs, and procedures that operations and maintenance personnel employ when the plant is not shutdown should be reviewed to verify that their design is consistent with the principles of good HFE design (e.g., conforms to a plant-specific style guide or NUREG-0700). • HSI Task-Support Verification – Temporary configurations of the systems, HSIs, and procedures, which operations and maintenance personnel may use when the plant is not shutdown, should be reviewed to verify that their design supports the intended tasks. – Additional Information: For example, if a temporary configuration of plant systems introduces special monitoring requirements, then the HSIs should give the necessary information. • ISV - Interim configurations should be validated if so warranted by the risk significance of the personnel tasks affected by them.	N/A, Section 5.0
12.4.2.4 Modernization Programs Where both Old and New Equipment are Left in Place 1. The applicant should identify and address negative effects on personnel performance due to control room or HSI clutter resulting from using old and new HSIs in parallel.	N/A, Section 5.0
2. The applicant should identify and address negative effects on personnel performance resulting from the simultaneous presence of parallel alarms.	N/A, Section 5.0
3. The applicant should identify and address negative effects on personnel performance resulting from differences in information from old and new systems on the same parameter or equipment.	N/A, Section 5.0
4. The applicant should identify and address any safety concerns from providing controls that operators can access from two different HSIs. Additional Information: For example, a switch may be installed to select which HSI will control the equipment, thus preventing simultaneous control inputs.	N/A, Section 5.0
12.4.2.5 Modernization Programs Where New Non-functional HSIs are in Place in Parallel with Old Functional HSIs 1. The applicant should evaluate the potential for negative effects on personnel performance due to control room or HSI clutter resulting from having old and new HSIs available in parallel. Where safety concerns are identified, the applicant should take measures to improve the HSIs.	N/A, Section 5.0
2. The applicant should ensure that the non-functional state of HSIs is clearly indicated.	N/A, Section 5.0

8.0 References

8.1 Source Documents

8.1.1 U.S. Nuclear Regulatory Commission, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition — Human Factors Engineering,” NUREG-0800, Chapter 18, Rev 2, March 2007.

8.2 Referenced Documents

8.2.1 Human Factors Engineering Program Management Plan, RP-0914-8534.

8.2.2 Human Factors Verification and Validation Implementation Plan, RP-0914-8543.

8.2.3 *U.S. Code of Federal Regulations*, “Changes, tests and experiments,” Section 50.59, Part 50, Title 10, “Energy,” (10 CFR 50.59).

8.2.4 U.S. Nuclear Regulatory Commission, “Human Factors Engineering Program Review Model,” NUREG-0711, Rev. 3, November 2012.

Enclosure 8:

Affidavit AF-1216-52041

NuScale Power, LLC

AFFIDAVIT of Carl Markert

I, Carl Markert, state as follows:

(1) I am the Vice President of Operations and Plant Services of NuScale Power, LLC (NuScale), and as such, I have been specifically delegated the function of reviewing the information described in this Affidavit that NuScale seeks to have withheld from public disclosure, and am authorized to apply for its withholding on behalf of NuScale

(2) I am knowledgeable of the criteria and procedures used by NuScale in designating information as a trade secret, privileged, or as confidential commercial or financial information. This request to withhold information from public disclosure is driven by one or more of the following:

(a) The information requested to be withheld reveals distinguishing aspects of a process (or component, structure, tool, method, etc.) whose use by NuScale competitors, without a license from NuScale, would constitute a competitive economic disadvantage to NuScale.

(b) The information requested to be withheld consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), and the application of the data secures a competitive economic advantage, as described more fully in paragraph 3 of this Affidavit.

(c) Use by a competitor of the information requested to be withheld would reduce the competitor's expenditure of resources, or improve its competitive position, in the design, manufacture, shipment, installation, assurance of quality, or licensing of a similar product.

(d) The information requested to be withheld reveals cost or price information, production capabilities, budget levels, or commercial strategies of NuScale.

(e) The information requested to be withheld consists of patentable ideas.

(3) Public disclosure of the information sought to be withheld is likely to cause substantial harm to NuScale's competitive position and foreclose or reduce the availability of profit-making opportunities. The accompanying human factors engineering (HFE) implementation plan, results summary reports, and Concept of Operations reveal distinguishing aspects about the process, methods, or other trade secrets by which NuScale develops and implements its human factors engineering program elements.

NuScale has performed significant research and evaluation to develop a basis for this process, methods, or other trade secrets and has invested significant resources, including the expenditure of a considerable sum of money.

The precise financial value of the information is difficult to quantify, but it is a key element of the design basis for a NuScale plant and, therefore, has substantial value to NuScale.

If the information were disclosed to the public, NuScale's competitors would have access to the information without purchasing the right to use it or having been required to undertake a similar expenditure of resources. Such disclosure would constitute a misappropriation of NuScale's intellectual property, and would deprive NuScale of the opportunity to exercise its competitive advantage to seek an adequate return on its investment.

(4) The information sought to be withheld is in the enclosures to NuScale letter from Thomas A. Bergman to the NRC, "NuScale Power, LLC Submittal of Third Set of Human Factors Engineering Documentation for Design Certification Application." The enclosures, Human Factors Verification and Validation Implementation Plan (RP-0914-8543), Human-System Interface Design Results Summary Report (RP-0316-17619), and Concept of Operations (RP-0215-10815), contain the

designation "Proprietary" at the top of each page containing proprietary information. The information considered by NuScale to be proprietary is identified within double braces, "{{ }}" in the document.

(5) The basis for proposing that the information be withheld is that NuScale treats the information as a trade secret, privileged, or as confidential commercial or financial information. NuScale relies upon the exemption from disclosure set forth in the Freedom of Information Act ("FOIA"), 5 USC § 552(b)(4), as well as exemptions applicable to the NRC under 10 CFR §§ 2.390(a)(4) and 9.17(a)(4).

(6) Pursuant to the provisions set forth in 10 CFR § 2.390(b)(4), the following is provided for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld:

(a) The information sought to be withheld is owned and has been held in confidence by NuScale.

(b) The information is of a sort customarily held in confidence by NuScale and, to the best of my knowledge and belief, consistently has been held in confidence by NuScale. The procedure for approval of external release of such information typically requires review by the staff manager, project manager, chief technology officer or other equivalent authority, or the manager of the cognizant marketing function (or his delegate), for technical content, competitive effect, and determination of the accuracy of the proprietary designation. Disclosures outside NuScale are limited to regulatory bodies, customers and potential customers and their agents, suppliers, licensees, and others with a legitimate need for the information, and then only in accordance with appropriate regulatory provisions or contractual agreements to maintain confidentiality.

(c) The information is being transmitted to and received by the NRC in confidence.

(d) No public disclosure of the information has been made, and it is not available in public sources. All disclosures to third parties, including any required transmittals to NRC, have been made, or must be made, pursuant to regulatory provisions or contractual agreements that provide for maintenance of the information in confidence.

(e) Public disclosure of the information is likely to cause substantial harm to the competitive position of NuScale, taking into account the value of the information to NuScale, the amount of effort and money expended by NuScale in developing the information, and the difficulty others would have in acquiring or duplicating the information. The information sought to be withheld is part of NuScale's technology that provides NuScale with a competitive advantage over other firms in the industry. NuScale has invested significant human and financial capital in developing this technology and NuScale believes it would be difficult for others to duplicate the technology without access to the information sought to be withheld.

I declare under penalty of perjury that the foregoing is true and correct. Executed on December 16, 2016.

Carl Markert