Enclosure 2:

"Human Factors Engineering Functional Requirements Analysis and Function Allocation Implementation Plan," RP-0914-8536-NP, Revision 1, Nonproprietary version

Human Factors Engineering Functional Requirements Analysis and Function Allocation Implementation Plan

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Revision 1

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NuScale Nonproprietary

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1.0 Introduction

1.1 Purpose

This document provides the functional requirements analysis (FRA) and function allocation (FA) implementation plan (IP) for the NuScale plant. Included in this document is a methodology for conducting FRA and FA. FRA is performed to ensure that the functions necessary to accomplish plant goals are sufficiently defined and analyzed so that the allocation of functions, subfunctions and controls can take advantage of human and machine strengths and avoid machine and human limitations. These allocations support subsequent task analysis, staffing analysis and development of human-system interfaces (HSI), procedures and training.

1.2 Scope

The NuScale reactor is a new and innovative modular passive pressurized water reactor design. Due to the uniqueness of this design, there is no commercial nuclear reactor that can be considered as its direct predecessor. Nonetheless, where NuScale functions differ from similar functions at traditional nuclear facilities, a basis for the difference is analyzed and documented in the FRA/FA database (see Section 3.1).

The NuScale FRA/FA applies to operations, maintenance, test, inspection, surveillance, and accident management functions involving the main control room (MCR), MCR-derivative HSIs, and local control stations.

1.3 Abbreviations and Definitions

Table 1-1. Abbreviations

Term	Definition
DHR	decay heat removal
EPRI	Electrical Power Research Institute
FA	function allocation
FRA	functional requirements analysis
HFE	human factors engineering
HFEITS	Human Factors Engineering Issue Tracking System
HSI	human-system interface
IP	implementation plan
MCR	main control room
NRC	Nuclear Regulatory Commission
OER	operating experience review
PRA	probabilistic risk assessment
SSC	structure, system, and component
TA	task analysis

2.0 Functional Requirements Analysis and Function Allocation Methodology

2.1 General Information

The Human Factors Engineering (HFE) Program includes FRA/FA as part of a series of analyses that relies primarily on design documents, subject matter experts, and operating experience. Functional requirements analysis is a resource for task analysis (TA), staffing and qualifications, and the development of human-system interfaces (HSI), procedures, and training; and there is feedback to FRA/FA from treatment of important human actions. {{

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2.2 Plant Functional Requirement Hierarchy Development

An early activity in the HFE program is to develop a plant functional requirement hierarchy. This plant functional requirement hierarchy is developed {{

}} Table 2-1 shows a hierarchical organization, which includes plant functions, plant goals, and the subfunctions that collectively accomplish the associated plant function. In this context, a subfunction may represent a process, system, system function, or component that is considered of sufficient breadth to contribute to accomplishing the associated plant function and warrant FRA/FA analysis.

Table 2-1. Simplified functional requirement hierarchy

Plant Function	Plant Goal	Subfunction Description
Reactivity management (RM)	Safety	RM subfunction 1
		RM subfunction 2
Maintain containment integrity (CI)	Safety	CI subfunction 1
		CI subfunction 2
Remove core heat (RH)	Safety	RH subfunction 1
		RH subfunction 2

Plant Function	Plant Goal	Subfunction Description
Thermal performance (TH)	Generate power	TH subfunction 1
		TH subfunction 2
		.....

Plant-level safety functions are defined, which, if successfully executed, accomplish the plant functional goals: 1) to ensure the health and safety of the public by preventing or mitigating the consequences of postulated accidents; and 2) to generate power (i.e., supply electricity to the grid). For the NuScale design, the plant-level safety functions are to

- control core reactivity
- maintain primary coolant inventory
- maintain reactor pressure control
- remove core heat
- maintain containment integrity

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The functional requirement hierarchy structure is organized and populated with appropriate subfunctions.

2.3 Hierarchy Updates and Comprehensive Gap Analysis

The plant functional requirement hierarchy is maintained as a representation of the current design by the design control process. Specific NuScale design documents (e.g., system descriptions, functional specifications) are reviewed by interdisciplinary HFE team members to ensure that significant plant design changes that may alter how plant functions accomplish goals are identified as HFE issues to be tracked in HFEITS (see Reference 8.2.1, Section 6.0). Changes to how plant functions accomplish goals are evaluated by the HFE team for potential changes to the plant functional hierarchy and any need to reperform FRA/FA. Issues are tracked to resolution via the HFEITS.

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2.4 Function Decomposition and Requirements Analysis

Members of the HFE team analyze each function within the FRA plant functions list to determine the appropriate level of automation.

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}}3(a)-(c) The HFE team documents in the FRA/FA database the following for each function:

- purpose of the function
- functions for systems similar to those used in other PWR designs
- Relevant operating experience
- differences from functions for systems similar to those used in other PWR designs
- supporting sub-functions
- supporting components
- support systems
- safety and risk significance

When the function decomposition is complete, the requirements analyses are conducted. {{

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As a result of the decomposition, investigation, and analysis, the HFE team documents (in the FRA/FA database) the following for each function:

- supported plant goal
- conditions that indicate the need for the function
- parameters that indicate the availability of the function
- parameters that indicate the operating status of the function
- parameters that indicate whether the function is achieving its purpose(s)
- parameters that indicate when the operations of the function can or should be terminated
- alternative success paths (required for safety-related functions)

The results and supporting documentation are reviewed by the HFE team and the results incorporated into the FRA/FA database. The detailed instructions for conducting FRA and the associated record requirements are contained in the Functional Requirements Analysis and Function Allocation Procedure (Reference 8.2.2).

2.5 Function Allocation

Function allocation starts with an allocation based on like or similar function allocations. The HFE team adjusts the allocation based on operating experience and initial allocation criteria, and then influences the allocation to improve safety, reliability, operator awareness, and cost effectiveness.

While there are some situations where function allocation is dictated by regulatory requirements; generally, no single criterion can be used to determine a function allocation. In most cases, the allocation represents the optimization of numerous relevant and sometimes conflicting criteria. Analysis of the criteria and evaluation of the level of automation allow the HFE team to allocate the function to the appropriate combination of automation and operator action.

2.5.1 Allocation Criteria

Allocation criteria represent considerations from a variety of differing perspectives where each criterion suggests a preferred allocation depending on its narrow perspective. Function allocation analysis identifies all relevant criteria to evaluate the function. Table 2-2 lists examples of commonly used criteria for function allocation.

Table 2-2. Criteria for function allocation

Examples of Criteria for Function Allocation	**If YES, Then Bias Towards:**
Operator capabilities	
Required response time too short for an operator to react?	automation
High probability of operator error?	automation
Repeated action distracts operator?	automation
Repeated action consumes too much of operator's time?	automation

Examples of Criteria for Function Allocation	**If YES, Then Bias Towards:**
Very precise control required?	automation
Functions, or parts of them, will be allocated to personnel when human knowledge and judgment are essential to ensure reliable system function performance.	operator
Can an operator maintain situation awareness with automated function?	automation
Machine or automation capabilities	
Automation of function is technically feasible?	automation
Automation of function is practical?	automation
Automation of function is cost-effective?	automation
Other criteria	
Are consequences acceptable for automation to backup operator functions that might be shed?	operator
Does function have existing practices?	existing practices
Operating experience analysis indicates function should be automated?	automation
Operating experience analysis indicates function should be manual?	operator
Operating experience review of operating nuclear facilities to assign allocation	lessons learned
Operating experience review of non-nuclear facilities to assign allocation	lessons learned
Does function have regulatory requirements?	per regulations
Safety-related system function reliability optimization?	automation
PRA risk significant function reliability optimization?	automation
Operator situation awareness must be optimized.	operator
Individual modules may be in different modes of operation (startup, shutdown, power operation or refueling).	automation
The aggregate of system functions allocated to one operator must be within their workload capability (counter objective to following objective).	automation
The aggregate of system functions allocated to one operator must allow the operator to remain vigilant (counter objective to previous objective).	operator
Operation by consent and operation by exception allocations allow operator involvement in the execution of a system function while still allowing automation to provide the primary execution of the function.	automation

Though Table 2-2 is intended as an example rather than description of NuScale automation criteria, it includes specific criteria associated with multi-unit, small modular reactor monitoring and control. These multi-unit criteria consider the preferred allocation of a function when implicit in a multi-unit plant; the allocation applies to each of the multiple units. When allocating a function to manual operation in a multi-unit plant, analysis and optimization consider the likelihood and consequence if an operator-

allocated function for one unit is delayed or shed (not performed) because of the requirement to perform a more urgent operator function for another unit.

2.5.2 Types of Function Allocation

Individual criteria, such as those shown in Table 2-2, consider a narrow point of view and do not consider varying degrees of automation or reflect the option to share a function between automation (the machine agent) and the operator (the human agent). In practice, allocations can employ a degree of both manual operation and automation. The ranges of allocations that are possible, including shared manual and automatic actions required to accomplish functions, are grouped to define the five types of function allocation contained in Table 2-3.

Table 2-3. Type of function allocations

Function Allocation Type	Automation Execution	Operator Execution
Manual operation	Automation does not execute any part of function	Operator manually executes function
Shared operation	Automation performs some portion of function	Operator performs some portion of function
Operation by consent	Automation performs function when directed by operator to do so	Operator pre-approves execution of function Operator monitors execution of function Operator may intervene with supervisory commands that automation executes
Operation by exception	Automation performs function autonomously until: reaching a critical automation step, or obtaining a system response identified by automation	Operator *does not* pre-approve execution of function Operator approves critical automation steps Operator may intervene with supervisory commands that automation executes
Automatic operation	Fully automatic operation	operator monitors execution of function operator may intervene and terminate automatic function if allowed by automation programming

2.5.3 Analysis and Optimization

Members of the HFE team analyze and then allocate each function to optimize relevant allocation criteria for each function as follows:

- Analyze function allocations and operating experience for plant systems and components similar to those used in other PWR designs.
- Analyze upstream and downstream functions and related functions elsewhere in the overall design to assess the indirect consequences of the allocation.
- Evaluate relevant criteria that may impact safety, reliability, situation awareness, and cost effectiveness.

- Evaluate the aggregate impact to personnel considering all functions allocated to them and adjust the allocation as necessary.
- Allocate the function to one of the types described in Table 2-3 to optimize relevant criteria, including safety, situation awareness, and those criteria described in Table 2-3.

Each function allocation, the allocation basis, and supporting documents are reviewed by the HFE team. The results are incorporated into the FRA/FA HFE database and functional requirement hierarchy chart tools described in Section 3.0. The detailed instructions for conducting function allocation and record requirements are contained in the Functional Requirements Analysis and Function Allocation Procedure (Reference 8.2.2).

2.5.4 Function Allocation Decision Making Criteria

Figure 2-1 shows the flowchart for function allocation decision making (Reference 8.2.4). Specific criteria for each point of decision are described in the FRA/FA procedure (Reference 8.2.2).

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Figure 2-1. Function allocation decision making

2.6 Activity and Information Flow

Figure 2-2 illustrates the flow of activities and information associated with FRA/FA.
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Figure 2-2. FRA/FA activity and information flow

2.7 FRA/FA Record Identification

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{{ }}[3(a)-(c)] The FRA/FA record and its review include the following:

- plant function
- function's purpose
- plant goal(s)
- plant subfunction(s) (if required)
- functions or systems for plant systems and components similar to those used in other PWR designs
- relevant operating experience
- differences from functions or systems for plant systems and components similar to those used in other PWR designs
- supporting processes
- supporting components
- support systems
- safety and risk significance
- conditions that indicate the need for the function
- parameters that indicate the availability of the function
- parameters that indicate the operating status of the function
- parameters that indicate whether the function is achieving its purpose
- parameters that indicate when the operations of the function can or should be terminated
- alternative success paths (where applicable)
- function allocation
- allocation basis
- relevant portions of the hierarchy chart
- plant function and related subfunction gap analysis

3.0 Functional Requirements Analysis and Function Allocation Tools

Two tools are used to record data from the FRA/FA processes.

The first tool is a FRA/FA database (VISION®). This database contains the results from the FRA/FA. This tool facilitates searches and reviews of past analysis. The database is used for other HFE program elements and product development as well, specifically, task analysis results, procedure development, and development of the knowledge and abilities catalog for the training program.

The second tool is a functional requirements hierarchy chart, which is a graphical representation of the data obtained from the analysis.

3.1 Functional Requirements Analysis and Function Allocation Database

Appropriate information from the applicable approved FRA/FA record for each function, goal and subfunction is entered into the FRA/FA database. The database includes the following information:

- plant function
- function's purpose
- plant subfunction(s) (if required)
- supporting subfunctions
- supporting processes
- supporting components
- support systems
- safety and risk significance
- conditions that indicate the need for the function
- parameters that indicate the availability of the function
- parameters that indicate the operating status of the function
- parameters that indicate whether the function is achieving its purpose
- parameters that indicate whether the operations of the function may or should be terminated.
- function allocation
- reference to FRA/FA document ID

3.2 Functional Requirement Hierarchy Chart

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Table 3-1. Example of the functional requirement hierarchy chart

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}}3(a)-(c) The functional hierarchy shown above is provided as an illustration only.

4.0 Functional Requirements Analysis and Function Allocation Support

4.1 HFE Team Organization and Qualification

The HFE team is responsible for conducting FRA/FA. The makeup of the FRA/FA team with regard to qualifications is described in the NuScale Human Factors Engineering Program Management Plan (Reference 8.2.1). The FRA/FA results summary report (see Section 6.0) defines and describes specific individuals who fulfilled the discipline qualifications (Table 3-1 of Reference 8.2.1) or from a unique need for certain functions. Resumes for those individuals associated with FRA/FA are maintained as quality assurance records.

4.2 HFE Issue Tracking

HFE issues, including those associated with FRA/FA, are tracked in the HFEITS database throughout the life cycle of the HFE program for the NuScale design project. The HFEITS database is described in the NuScale Human Factors Engineering Program Management Plan (Reference 8.2.1).

5.0 Additional Considerations for Plant Modifications

As the NuScale HFE program applies to the design of a new plant, there are additional considerations for reviewing the HFE aspects of plant modifications during FRA/FA. The NuScale Human Performance Monitoring IP (Reference 8.2.3) has provision for and describes appropriate processes for design changes occurring after turnover to the licensee.

6.0 Functional Requirement Analysis and Function Allocation Results Summary Report

When the FRA/FA is complete, NuScale provides a results summary report to the NRC containing the following information:

- the methodology used to identify the system safety and risk significant function
- a complete set of safety-related, risk-significant and other plant functions
- a complete set of functional requirements necessary to satisfy plant goals
- the methodology used to allocate functions
- the function allocations and technical basis for those allocations
- identification of how personnel and automatic systems perform the functions
- the basis for NuScale functions that differ from similar functions at traditional nuclear facilities
- functional Requirements Analysis and Function Allocation Team member technical discipline involvement and qualifications for individuals

7.0 NUREG-0711 Conformance Evaluation

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

Table 7-1. Conformance with NUREG-0711

Review Criteria Stated in NUREG-0711, Rev. 3	**FRA/FA IP Section No. and Paragraph**
4.4 Review Criteria (1) The applicant should use a structured, documented methodology reflecting HFE principles to perform FRA and FA. *Additional Information:* The FRA and FA may be graded based on: • The degree to which the functions of the new design differ from those of its predecessor(s) • The extent to which problems in operating experience were encountered for the plant's functions in predecessor plants	Section 3.0 Section 3.4, paragraph 2; Section 3.5, paragraph 1 Section 3.4, paragraph 2; Section 3.5, paragraph 1; Table 3-2
(2) The applicant's FRA and FA should be performed iteratively to keep it current during design development and operation up to decommissioning, so that it can be used as a design basis when modifications are considered.	Section 3.1; Figure 3-1, Figure 3-2
(3) The applicant should describe the plant's functional hierarchy, including, as appropriate goals, functions, processes, and systems. The description should include • Comparing them with the predecessor or reference plants and systems, i.e., the previous ones on which the new plant is based • Identifying the differences between the proposed and reference plants and systems • Documenting the technical basis for modifications to high-level functions in the new design (compared to the predecessor design) • Defining, for each safety function and other plant function (e.g., electrical power generation), the set of system configurations or success paths that are responsible for, or able to carry out the function • Decomposing the functions, starting at "high-level" functions where a very general picture of major functions is described, and continuing to lower levels, until a specific critical end-item requirement emerges (e.g., a piece of equipment, software, or a human action (HA). The functional decomposition should address the following levels – high-level functions (e.g., maintain reactor coolant system integrity)	Section 3.2, all paragraphs; details included in RSR

Review Criteria Stated in NUREG-0711, Rev. 3	**FRA/FA IP Section No. and Paragraph**
– the processes, as appropriate, that enable achievement of these functions – specific plant systems and components – HAs, as appropriate *Additional Information*: Safety functions (e.g., reactivity control) include functions needed to prevent or mitigate the consequences of postulated accidents that could pose undue risk to the public's health and safety. Important human actions will be further evaluated in the task analyses.	
(4) For each high-level function, the applicant should identify requirements related to • Purpose of the high-level function • Conditions indicating that the high-level function is needed • Parameters indicating that the high-level function is available • Parameters indicating that the high-level function is operating (e.g., flow indication) • Parameters indicating that the high-level function is achieving its purpose (e.g., reactor vessel level returning to normal) • Parameters indicating that the operation of the high-level function can or should be terminated *Additional Information*: At this stage, parameters may be described qualitatively (e.g., high or low). Specific data values or setpoints are not necessary.	Sections 3.3 and 3.4, all paragraphs

Review Criteria Stated in NUREG-0711, Rev. 3	FRA/FA IP Section No. and Paragraph
(5) Applicants should allocate functions to a level of automation (e.g., from manual to fully automatic) and identify the technical bases for the allocations. *Additional Information:* The technical basis for the FA can be any one or combination of the factors (see Figure 4-2). For example: • Functions, or parts of them, may be allocated based on operating experience. Successful operating experience may suggest keeping allocations the same as in predecessor designs and operating experience issues may suggest changing the allocations to address the issues. • Functions, or parts of them, may be allocated to automation when their performance requirements exceed human capabilities and human error is likely. Conditions that establish a basis for automation (assuming the acceptability of other factors, such as technical feasibility or cost) include when the required response time is very short, when an action has to be performed repeatedly, or when very precise control is required. • Functions, or parts of them, should be allocated to personnel when human knowledge and judgment is needed to ensure reliable function performance, it is important to keep personnel involved in the actions so they have good situation awareness should they need to perform the function, or to preclude boredom.	Section 3.5, all; Tables 3-2 and 3-3; Figure 3-1
(6) The applicant's FA should consider not only the primary allocations to personnel (those functions for which personnel have the primary responsibility), but also their responsibilities to monitor automatic functions, detect degradations and failures, and to assume manual control when necessary.	Section 3.5, all; Tables 3-2 and 3-3; Figure 3-1
(7) The applicant should describe the overall role of personnel by considering all functions allocated to them. *Additional Information*: The FA to personnel and automation is considered on a function-by-function basis. However, the overall personnel role is an aggregate of all functions allocated to them. While on an individual basis, a single function allocation to personnel may be justified, allocations should also be considered in the context of other responsibilities personnel have to help ensure that together all functions allocated to personnel are acceptable and do not interfere with each other.	Sections 3.5.1, 3.5.2 and 3.5.3; Tables 3-2 and 3-3

Review Criteria Stated in NUREG-0711, Rev. 3	**FRA/FA IP Section No. and Paragraph**
(8) The applicant should verify that the FRA and FA accomplish the following: • All the high-level functions needed to achieve safe operation are identified • all requirements of each high-level function are identified • the allocation of functions to humans and automatic systems assures a role for personnel that takes advantage of human strengths and avoids human limitations	Sections 3.5.3, 3.6, 3.7 and 4.0
(9) 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 FRA should address new functions resulting from changes in the degree of integration between plant systems. • *Additional Information*: The FRA for modifications may change existing safety functions or introduce new functions for systems supporting them. For example, installing higher-level automation may bring systems formerly controlled separately under a single controller. Also, the modifications may change the degree to which different plant systems share common resources (e.g., power, cooling water, and data-transmission buses). These may be important in diagnosing malfunctions or planning responses. • The FRA should be revised and updated to reflect the modification. The scope of the FRA may be restricted to functions related to the modification. • The FA should be revised and updated to reflect modifications that are likely to change the allocation between personnel and plant systems of functions important to safety. The scope of the analyses may be restricted to functions involving the modification. • A change in the role of personnel due to a modification should be examined within the context of its effects on their overall responsibilities. *Additional Information*: Increases in certain task demands may affect the ability of personnel to carry out other actions categorized as important (see Section 7).	Section 6.0

8.0 References

8.1 Source Documents

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

8.1.2 *U.S. Code of Federal Regulations*, "Contents of applications; technical information," Section 50.34, Part 50, Chapter 1, Title 10, "Energy," (10 CFR 50.34).

8.1.3 *U.S. Code of Federal Regulations*, "Emergency plans," Section 50.47, Part 50, Chapter 1, Title 10, "Energy," (10 CFR 50.47).

8.1.4 *U.S. Code of Federal Regulations*, "Requirements for physical protection of licensed activities in nuclear power reactors against radiological sabotage," Section 73.55, Part 73, Chapter 1, Title 10, "Energy," (10 CFR 73.55).

8.1.5 O'Hara, J. and J. Higgins, "NRC Reviewer Aid for Evaluating the Human Factors Engineering Aspects of Small Modular Reactors," Brookhaven National Laboratories, January 13, 2012.

8.2 Referenced Documents

8.2.1 NuScale Human Factors Engineering Project Management Plan, RP-0914-0834-P.

8.2.2 NuScale Functional Requirements Analysis and Function Allocation Procedure, EP-0303-2130, [in development].

8.2.3 NuScale Human Factors Engineering Human Performance Monitoring Implementation Plan, RP-0914-8545.

8.2.4 U.S Nuclear Regulatory Commission, "A Methodology for Allocating Nuclear Power Plant Control Functions to Human or Automatic Control," NUREG/CR-3331, August 1983.