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May 17, 2019 Docket No. 52-048

U.S. Nuclear Regulatory Commission
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SUBJECT: NuScale Power, LLC Submittal of “Nuclear Steam Supply System Advanced Sensor Technical Report,” TR-0316-22048, Revision 2

REFERENCES:
1. Letter from NuScale Power, LLC to U.S. Nuclear Regulatory Commission, “Submittal of Technical Reports supporting the NuScale Design Certification Application,” dated December 29, 2016 (ML17005A112)
2. NuScale Technical Report, “Nuclear Steam Supply System Advanced Sensor Technical Report,” Revision 0, TR-0316-22048, dated December 2017 (ML17005A126)
3. Letter from NuScale Power, LLC to U.S. Nuclear Regulatory Commission, “Submittal of Nuclear Steam Supply System Advanced Sensor Technical Report,” Revision 1, TR-0316-22048, dated September 28, 2018 (ML18274A392)

NuScale Power, LLC (NuScale) hereby submits Revision 2 of the “Nuclear Steam Supply System Advanced Sensor Technical Report,” (TR-0316-22048). The purpose of this submittal is to request that the NRC review and approve the NuScale nuclear steam supply system advanced sensor selection approach.

Enclosure 1 contains the proprietary version of the report entitled “Nuclear Steam Supply System Advanced Sensor Technical Report.” NuScale requests that the proprietary version be withheld from public disclosure in accordance with the requirements of 10 CFR § 2.390. The enclosed affidavit (Enclosure 3) supports this request. Enclosure 1 has also been determined to contain Export Controlled Information. This information must be protected from disclosure per the requirements of 10 CFR § 810. Enclosure 2 contains the nonproprietary version of the report entitled “Nuclear Steam Supply System Advanced Sensor Technical Report.”

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

If you have any questions, please contact Marty Bryan at 541-452-7172 or at mbryan@nuscalepower.com.

Sincerely,

Thomas A. Bergman
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Enclosure 1: "Nuclear Steam Supply System Advanced Sensor Technical Report," TR-0316-22048, Revision 2, proprietary version

Enclosure 2: "Nuclear Steam Supply System Advanced Sensor Technical Report," TR-0316-22048, Revision 2 , nonproprietary version

Enclosure 3: Affidavit of Thomas A. Bergman, AF-0519-65562

Enclosure 1:

“Nuclear Steam Supply System Advanced Sensor Technical Report,” TR-0316-22048, Revision 2, proprietary version

Enclosure 2:

“Nuclear Steam Supply System Advanced Sensor Technical Report,” TR-0316-22048, Revision 2, nonproprietary version

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Licensing Technical Report

Nuclear Steam Supply System Advanced Sensor Technical Report

May 2019

Revision 2

Docket: 52-048

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Abstract

The NuScale Power, LLC (NuScale) design poses unique challenges for sensor selection because of its small size, integral pressurized water reactor vessel, and high pressure containment. This document describes NuScale's approach to assure that the appropriate temperature, pressure, flow and level sensors are selected on the basis of their requirements, operation, installation, maintenance, and qualification. The approach draws on requirements identified in NuScale documents, safety analyses, Nuclear Regulatory Commission (NRC) design criteria, American Society of Mechanical Engineers (ASME) standards, and Institute of Electrical and Electronics Engineers (IEEE) standards. This report addresses all vessel-related sensor types being considered for use in the NuScale small modular reactor.

Executive Summary

The NuScale Power, LLC (NuScale) design poses unique challenges for sensor selection because of its small size, integral pressurized water reactor vessel, and high pressure containment. This document describes NuScale's approach to assure that the appropriate temperature, pressure, flow and level sensors are selected on the basis of their requirements, operation, installation, maintenance, and qualification. The approach draws on requirements identified in NuScale documents, safety analyses, Nuclear Regulatory Commission (NRC) design criteria, American Society of Mechanical Engineers (ASME) standards, and Institute of Electrical and Electronics Engineers (IEEE) standards. This report addresses all vessel-related sensor types being considered for use in the NuScale small modular reactor.

The NSSS sensors that are adjacent to the reactor pressure vessel (RPV), the containment vessel (CNV), or associated piping on the vessel side of the NuScale Power Module (NPM) of any disconnection point, are included in this report. The report also includes the under-the-bioshield temperature sensors that are mounted to the module operating bay reactor pool wall. Feedwater isolation valve position indication has been added as a safety-related sensor input, but is treated as a component of the feedwater system and is not included in this report. Functions associated with the NPM sensors are included in this report. Those functions include post-accident monitoring (PAM), reactor trip systems (RTS), engineered safety features actuation system (ESFAS), low temperature overpressure protection (LTOP), core cooling indications, main control room (MCR) indication, alarms, plant historian, and NSSS control.

As an initial part of the sensor selection process, a habitability study was performed to evaluate the NSSS sensor and associated transmitter locations for survivability in the NPM. This study used estimated values for temperature, pressure, and radiation to assess the viability of conventional sensor use in the NPM. Under normal conditions, the small size of the CNV and RPV creates a unique environment. The instrumentation experiences a more severe temperature and radiation environment than the instrumentation used in a conventional pressurized water reactor. In the event of a design-basis accident (DBA), the radiation, temperature, and pressure levels in the CNV become significantly higher, which creates a unique environment in which the safety-related instrumentation must continue to function.

After analyzing multiple options, the conclusion from the habitability study was that the most suitable solution for instrumenting the NPM would be to find, or manufacture, radiation-hardened sensors paired with remote electronics located outside the bioshield area.

To overcome the aspects of the NPM small size and restrictive environment, NuScale is implementing a four-phase approach for sensor selection as follows:

- Phase 1 - Technology Selection
- Phase 2 – Proof-of-Concept
- Phase 3 - Collaborative Product Development
- Phase 4 – Environmental Qualification

Phase 1 has been completed for the four primary process variables of interest: temperature, flow, pressure, and level. This technical report discusses the results of Phase 1 for each of the process variables.

Phase 2 for reactor coolant system (RCS) flow measurement, pressurizer (PZR) level, RPV riser level measurement, CNV water level measurement, and pressure measurement is {{ }}2(a),(b) The Phase 2 evaluation for resistance temperature detectors (RTDs) is not needed because RTDs are an existing nuclear qualified device and are expected to meet the NuScale predicted environments with minimal modification.

{{

}}2(a),(b)

NuScale locates some of the NPM sensors adjacent to the RPV, most of which are in the CNV, and plans to use first-of-a-kind (FOAK) nuclear sensor technology that may contain digital signal processing equipment. This report addresses the path taken to-date and describes the FOAK technologies as well as the conventional technologies to be utilized. This report describes the sensor technologies and their functions, maintenance, installation, qualification, and future work.

The sensor descriptions of the valve position indications, the neutron monitoring system (ex-core) sensors, the in-core instrumentation, the PAM radiation monitors, the bus voltage monitors, and the control rod position indication sensors are provided by their respective manufacturers or system owners and are not within the scope of this report because they are mature technologies.

Temperature Measurement

Temperature, pressure, and radiation levels in the NPM containment are higher than in conventional large pressurized water reactors, {{ }}2(a),(c) The Phase 1 report for temperature measurement recommended {{

}}2(a),(c)

Pressure Measurement

An unconventional pressure measurement device was selected that provided an in-containment method of measuring pressure. This device uses a pressure transducer mounted inside containment with remote processing electronics. {{

}}2(a),(c) and environmental qualification.

Flow Measurement

The {{ }}2(a),(c),(d) has been selected to measure RCS flow. The {{

}}2(a),(c),(d) was contracted to perform a Phase 1 preliminary evaluation of their {{ }}2(a),(c) could be converted and installed on the NuScale vessel to measure RCS flow. The results of Phase 1 justified proceeding to a Phase 2 proof-of-concept study.

As part of the Phase 2 flow measurement project, a {{

}}2(b),(c)

Level Measurement

A Phase 1 study was undertaken to explore methods for the measurement of containment water level, pressurizer level, and RPV riser reactor level. Radar technology was selected from the Phase 1 study as the best solution for level measurement for the NuScale design. Radar is currently used throughout the nuclear industry to measure spent fuel pool water level and has promising accuracy capability for the required level measurements within the NPM.

The baseline level measurement concept being pursued for the NuScale design is a radar device implemented in conjunction with a guide tube or probe for containing the signal. The processing electronics for the radar unit is remote from the sensor assembly and located in a mild environment.

Summary

Sensor development for the new unconventional sensor functions is underway. Current NuScale contracts with companies such as {{ }}2(c),(d) Ultra Electronics are pursuing this work. As the sensor requirements and concept design become more mature, the details of this sensor definition will be captured in updated revisions of this document, in the appropriate drawings, and in the respective system design description documents.

1.0 Introduction

1.1 Purpose

The purpose of this Nuclear Steam Supply System (NSSS) Advanced Sensor Technical Report is to describe NSSS sensor requirements, design concepts, performance capabilities, locations, maintenance approach, and qualification plans. This report also identifies the areas that need further investigation or study. The information contained in this report is the latest definition and understanding of NSSS sensors. It draws on requirements identified in NuScale documents, safety analyses, NRC design criteria, and industry standards.

1.2 Scope

This technical report describes the approaches NuScale has taken to measure the NSSS process variables: flow, temperature, pressure, and level. This report addresses the work accomplished to-date, the first-of-a-kind (FOAK) technologies, and the conventional technologies to be utilized. This report describes sensor technology, its applications, maintenance, installation, and spares philosophy, which are based on the NuScale environmental specifications for containment, reactor pool, and under-the-bioshield environments. Feedwater isolation valve position indication has been added as a safety-related sensor input, but is treated as a component of the feedwater system and is not included in this report.

Functions associated with the NSSS sensors are included in this report. Those functions include post-accident monitoring (PAM), {{

}}2(c)

The development process for each sensor function is outlined below. The items that need further development or research are identified at the end of each sensor description in a section entitled Future Work. These items identify instrumentation scope for follow-on internal NuScale engineering work and external vendor contracts.

The sensor descriptions of the valve position indications, the neutron monitoring system (ex-core) sensors, the in-core instrumentation, the PAM radiation monitors, the voltage monitoring sensors, and the rod position indication sensors are provided by their respective manufacturers or systems and are not included in the scope of this report.

This report is divided into sensor functional groups: temperature, pressure, flow, and level. The following topics are developed within each sensor group:

- Sensor Requirements
- Sensor Functions
- Sensor Description

  - Location
  - Installation
  - Maintenance
  - Qualification
- Future Work

1.3 Abbreviations

Table 1-1 Abbreviations

Term	Definition
10 CFR 50	Title 10, Code of Federal Regulations, Part 50
ASME	American Society of Mechanical Engineers
CCF	common-cause failure
CFD	computational fluid dynamics
CNV	containment vessel
CVCS	chemical and volume control system
DBA	design basis accident
DBE	design basis event
DHR	decay heat removal
DHRS	decay heat removal system
EPA	electrical penetration assembly
ESFAS	engineered safety feature actuation system
FOAK	first-of-a-kind
FW	feedwater
FWIV	feedwater isolation valve
GDC	general design criteria
I&C	instrumentation and controls
ICI	in-core instrumentation
IEEE	Institute of Electrical and Electronics Engineers
{{	}}[2(a),(c)]
LTOP	low temperature over-pressure protection
MCR	main control room
MCS	module control system
MI	mineral insulated
MPS	module protection system
MS	main steam
MSIV	main steam isolation valve
NPM	NuScale Power Module
NR	narrow range
NRC	Nuclear Regulatory Commission

Term	Definition
NSSS	nuclear steam supply system
PAM	post-accident monitoring
psia	pounds per square inch absolute
PZR	pressurizer
RCS	reactor coolant system
RG	Regulatory Guide
RPV	reactor pressure vessel
RTD	resistance temperature detector
RTS	reactor trip system
SG	steam generator
WR	wide range
°F	degree Fahrenheit
%	percent

Table 1-2 Definitions

Term	Definition
NSSS control	NSSS control is the control system that regulates and controls plant parameters for normal operation, specified operational transients, and plant unanticipated events. These control loops include reactor control, pressurizer level and pressure control, feedwater and main steam control, as well as many others. In the NuScale nomenclature, the NSSS control system is referred to as the module control system (MCS).
sensor accuracy	Sensor accuracy in this report is a value arrived at by engineering judgment based on known or similar sensor reference accuracies including estimated drift and temperature effects. It does not include measurement and test equipment (M&TE) uncertainties, process uncertainties, or any uncertainties contributed by other equipment in the loop.
T_{hot}	The reactor cooling water temperature at the top of the RPV riser assembly (beneath the pressurizer baffle plate)
T_{cold}	The temperature of the reactor cooling water below the steam generators
top of containment	The area inside containment in the top ¼ of the containment vessel
underneath the bioshield	The area outside containment, on the top section above the reactor pool water level and underneath the bioshield

2.0 Background

The NuScale Power Module (NPM) is an innovative design based on over 50 years of practical application of light water-cooled pressurized water reactor technology. The NPM is a self-contained system composed of a reactor core, a pressurizer (PZR), and two steam generators (SG) integrated within the reactor pressure vessel (RPV) and housed in a compact steel containment vessel (CNV). The NPM is designed to operate efficiently at full-power conditions using natural circulation as the means of providing core coolant flow, eliminating the need for reactor coolant pumps. The NPM is partially immersed in a reactor pool and protected by passive safety systems.

The small size of the CNV creates unique constraints in that most of the instrumentation is located in the RPV and the CNV and is in close proximity to radiation and high temperature under normal conditions. Under these conditions, the instrumentation experiences a more severe environment than the instrumentation in a conventional pressurized water reactor. In the event of a design-basis accident, the radiation levels in the CNV become significantly higher, which creates a unique environment in which the instrumentation must continue to function.

NuScale developed a habitability report that addressed the survivability and habitability of sensors located in containment and underneath the bioshield, based on environmental specifications. This report showed that the in-containment enclosure approach to sensor habitability, which was part of the previous baseline design, would not provide the temperature or radiation protection required to locate conventional pressure sensors in containment.

In addition to sensor research and development, NuScale investigated a design for a connector that is capable of withstanding the NuScale containment temperatures and pressures while providing a hermetically sealed electrical connection. This connector is used to provide the sensor to cable connection in containment. It may also be used outside of containment. The connector is designed to be made of materials that are radiation tolerant.

Research into sustainable electric cables that could operate in the containment environment was also pursued. A Phase 1 report was issued that recommended mineral insulated (MI) cables for all cabling inside containment.

To overcome the difficulties associated with providing instrumentation for the vessel, NuScale implemented a four-phase process for sensor selection as follows.

Phase 1 – The intent of Phase 1 was to perform an industry wide review of the instrumentation available for each of the four process variables with the goal of selecting instruments or types of instruments that appear to be eligible for qualification and to meet the process requirements associated with the NPM.

Phase 2 is a "proof-of-concept" phase performing tests on the instruments selected in Phase 1 to validate their ability to meet the criteria for service in the NPM excluding environmental qualification. Phase 2 developments for RCS flow measurement, pressurizer level, RPV riser level measurements, containment water level, and vessel-related pressure measurement are {{ }}2(a),(b) Because nuclear qualified resistance temperature detectors (RTD) were selected for temperature measurement, no Phase 2 proof-of-concept is necessary for temperature measurement. RTD development proceeds directly to Phase 3.

Phase 3 involves collaborative product development between NuScale and the selected vendor for each process variable to prepare the instruments for qualification. Phase 3 schedules for the {{ }}2(c)

Phase 4 is used to qualify the various instruments for harsh environment service in the NPM. A {{ }}2(a),(b) Radiation aging, including design basis event dose, consumes the greatest amount of time in the qualification process. NuScale has new qualification programs for some sensors that use FOAK sensor technology and experience new pressure, temperature, and radiation environments.

2.1 Technology

Conventional sensing technology was analyzed initially to maximize the experience and qualification of currently fielded devices; however, in many cases the conventional devices did not offer viable solutions for the NuScale containment environment. At the conclusion of the Phase 1 studies, conventional technology was chosen for temperature sensors and sensors located outside of containment. Other sensors located inside containment required new technology solutions. The new technology sensing methods are detailed in this report.

2.2 Spares

In general, no installed spares are utilized in any measurement requirement. This decision was to minimize the number of in-containment and near containment sensors and to minimize cables going through the containment penetrations. If an in-containment sensor requires replacement, the only opportunity is in the refueling dry dock.

The exceptions to this are the temperature sensors. Generally, RTDs are constructed with two elements per sensor assembly. This allows incorporating an installed spare without requiring installation of additional thermowells or sensors. It also allows the use of a single sensor for wide range and narrow range instruments for RCS hot and cold temperatures.

The narrow range RCS hot and cold temperatures also utilize multiple sensors in each separation group. This was done to develop an averaging process to minimize temperature streaming effects in the RPV riser (RCS hot temperature) and the downcomer (RCS cold temperature). The processing system can also be configured to drop out a failed RTD from the average, making the system capable of sustaining an on-line failure with no interruption in service.

2.3 Assumptions and Design Guidance

The following assumptions are applicable to the NuScale advanced sensors described in this report.

- All instruments are accessible, retrievable, and replaceable while in the refueling bay dry dock.
- All in-vessel instruments described shall be capable of calibration and capable of an in-situ function test upon vessel return to the operating bay.
- Space is provided for electronics associated with sensors on or near the platform, above the containment head if required, or in an electronics room.
- Sensors located in the top of containment or underneath the bioshield are protected, shielded, or located away from the impact spray effects of a high energy line break by pipe whip restraints, local shielding, or sensor location.
- The decay heat removal system (DHRS) condenser is capable of supporting the mass of the submerged pressure, temperature, and level sensors.

The following design guidance applies to the design of the NuScale advanced sensors.

- Taps or sensing lines through the containment vessel wall are not possible without moving the containment pressure boundary around them or adding double isolation.
- The vessel sensors meet the requirements of 10 CFR 50.34(f)(2)(xviii), Reference 9.1.2, in regards to providing an unambiguous indication of inadequate core cooling.
- The sensor accuracy and sensor response time requirements detailed in this report are the result of {{

  }}2(a),(c)
- All sensor supporting structures planned for insertion in the RPV (as part of the RPV pressure boundary) are classified as Seismic Category I. The seismic requirement classification in sections 4, 5, 6, and 7 of this report is for the sensor or sensing element only and does not apply to the thermowells, guide tubes, or other sensor supporting structures.

2.4 Alternative Sensor Options

Through the process of investigation of suitable sensors for the NPM design, many technologies were investigated. A Phase 1 contract {{ }}2(c),(d)

{{

}}2(c),(d) Many of these technologies showed promise for NPM sensor measurements; however, they were not chosen as the baseline option due to the immaturity of design or potential for increased development risk. These technologies remain as back-up options for the NuScale design, in the event that a current baseline option becomes unsuitable.

2.5 Regulatory Acceptance Criteria and Guidance

- Title 10, Code of Federal Regulations, Part 50 (10 CFR 50), Appendix A, General Design Criteria (GDC) 2 “Design Basis for Protection Against Natural Phenomena” sets requirements for the qualification of structures, systems, and components important to safety in the event of earthquakes, tornadoes, hurricanes, floods, tsunami, and seiches.
- 10 CFR 50, Appendix A, GDC 4, “Environmental and Dynamic Effects Design Bases” sets the requirements for systems, structures, and components important to safety such that they are designed to accommodate the effects of environmental conditions associated with normal operations, maintenance, testing, and postulated accidents.
- 10 CFR 50, Appendix A, GDC 13, "Instrumentation and Control" requires, in part, instrumentation to monitor variables and systems over their anticipated ranges for normal operation, anticipated operational occurrences, and for accident conditions as appropriate to assure adequate safety.
- 10 CFR 50.49, “Environmental Qualification of Electric Equipment Important to Safety for Nuclear Power Plants” sets the qualification requirements for instrumentation and controls (I&C) equipment in harsh environments. Regulatory Guide (RG) 1.89, Revision 1, “Qualification of Class 1E Equipment for Nuclear Power Plants,” provides methods found acceptable by the NRC for complying with the requirements of 10 CFR 50.49. RG 1.89 endorses IEEE Standard 323-1974, “Qualifying Class 1E Equipment for Nuclear Power Generating Station” as accepted guidance on equipment qualification for harsh environments.
- U.S. NRC RG 1.209, “Guidelines for Environmental Qualification of Safety-Related Computer Based Instrumentation and Control Systems in Nuclear Power Plants,” specifies additional requirements for safety related digital I&C components located in a mild environment. RG 1.209 endorses IEEE Standard 323-2003 “IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations,” as accepted guidance on equipment qualification for mild environments.
- U.S. NRC RG 1.206, “Combined License Applications for Nuclear Power Plants,” June 2007, notes in Section C.I.1.5 that the NRC expects additional technical information (beyond that in the application), including items such as verification of unique design concepts.

- 10 CFR 52.47, "Contents of Applications; Technical Information," specifies that an application must contain a sufficient level of design information. 10 CFR 52.47(a)(2)(i) puts emphasis on the extent to which the reactor incorporates unique, unusual or enhanced safety features having a significant bearing on the probability or consequences of accidental release of radioactive materials.
- IEEE Standard 379-2000, "Application of the Single-Failure Criterion to Nuclear Power Generating Station Safety Systems," provides methods acceptable to the NRC staff for satisfying the NRC regulations with respect to the application of the single-failure criterion to the electrical power, instrumentation, and control portions of nuclear power plant safety systems. RG 1.53, Revision 2, "Application of the Single-Failure Criterion to Safety Systems," endorses IEEE Standard 379-2000 as accepted guidance for satisfying the single failure criterion.
- IEEE Standard 344-2004, "IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations," provides generally accepted methods for the seismic qualification of electrical equipment in new nuclear power plants. RG 1.100, Revision 2, "Seismic Qualification of Electrical and Active Mechanical Equipment and Functional Qualification of Active Mechanical Equipment for Nuclear Power Plants," endorses IEEE Standard 344-2004 as accepted guidance for the seismic qualification of electrical equipment.
- IEEE Standard 603-1991, "IEEE Standard Criteria for Safety Systems for Nuclear Power Generating Stations," section 5.4 requires that safety equipment be qualified by type test, previous operating experience, or analysis, or any combination of these three methods. IEEE Standard 603-1991 is incorporated by reference into 10 CFR 50.55a(h), "Protection and safety systems."
- IEEE Standard 7.4.3.2-2003, "IEEE Standard Criteria for Digital Computers in Safety Systems of Nuclear Power Generating Stations," section 5.4 provides additional guidance for the qualification of digital I&C equipment. RG 1.152, Revision 3, "Criteria for Use of Computers in Safety Systems of Nuclear Power Plants," endorses IEEE Standard 7.4.3.2-2003.

3.0 Instrumentation Selection Process

3.1 Phase 1

In 2015, Ultra Electronics, Nuclear Sensors and Process Instrumentation (hereinafter referred to as Ultra Electronics), performed a Phase 1 study for sensor technology selection for each of the four process variables and the results of those studies constitute part of the basis for this report. Additional studies were performed for NuScale on instrument habitability in the containment, pressure measurement options, level measurement options, MI and other hardened cables, temperature measurement, and an in-vessel connector concept. Ultra Electronics was selected for their decades-long experience in nuclear plant instrumentation and their ability to engineer and re-engineer unique nuclear quality sensors. NuScale has worked with Ultra Electronics since 2012, when the vendor first started considering in-vessel instrumentation that would work with the NuScale design. Ultra Electronics has an established 10 CFR 50, Appendix B Nuclear Quality program, and they have the resources and facilities to design, build, and qualify nuclear instrumentation.

During the period 2014 through 2015, {{ }}[2(a),(c),(d)] Based on the Phase 1 results, NuScale has proceeded with a Phase 2 {{ }}[2(a),(b)]

3.2 Phase 2

The RCS flow instrumentation is actively undergoing Phase 2 development at this time. {{ }}[2(a),(b)] obtaining data over flow ranges corresponding to 0 percent to 110 percent of estimated full flow. The testing verified that the design could perform as required. Further testing will be conducted to determine if uncertainties can be reduced using different sensor locations and configurations.

{{ }}[2(a),(b)]

A contract has been issued for Phase 2 development of RPV and CNV level. The intent of this phase is to analyze and test various commercially available systems, with the objective of choosing the product(s) for use in the NPM. Ultra Electronics, as the overseer of the test effort, is responsible for constructing test chambers and testing various level detectors to determine which models for further development. Ultra Electronics is also responsible for evaluating {{ }}[2(a),(c)] An additional part of the Phase 2 effort is currently planned for testing the ability of systems to accurately measure level under operating temperature and pressure.

A radiation hardened and temperature tolerant pressure transducer with remote electronics was recommended for in-vessel pressure measurement in the pressure report in Phase 1. Several product options were recommended for this sensor selection. Once the sensor selection is complete, Phase 2 work will begin on in-vessel pressure sensing devices.

RTDs that are currently available were selected for temperature measurement. Consequently, no proof-of-concept phase (i.e., Phase 2) is needed for them.

3.3 Phase 3 and Phase 4

There are {{

}}2(a),(b)

4.0 Temperature Measurement in the NPM

The purpose of the Phase 1 temperature study for NuScale was to present conceptual designs for in-vessel temperature measurement that meets the requirements of the NPM. The scope of the report was to develop approaches for measuring the following.

1. Narrow range RCS hot temperature (NR RCS T_{hot})
2. Wide range RCS hot temperature (WR RCS T_{hot})
3. Narrow range RCS cold temperature (NR RCS T_{cold})
4. Wide range RCS cold temperature (WR RCS T_{cold})
5. Pressurizer liquid temperature
6. Pressurizer vapor temperature
7. CNV air temperature
8. Main steam (MS) temperature
9. Feedwater temperature
10. DHRS outlet temperature
11. Under-the-bioshield temperature

RTDs in the NuScale RPV design are mounted in thermowells to isolate the sensing elements from the process environment. Therefore, pressure and temperature environment for environmental qualification is limited to the conditions for the exterior portion of the RTD located in containment.

Table 4-1 Temperature Sensor List

Temperature Sensors	Range	Quantity	Function	Location	Safety and Risk Classification
Narrow range RCS hot temperature	400°F to 650°F	12	RTS ESFAS T-4 interlock NSSS control MCR indication Input to calorimetric calculation Plant historian	Top of downcomer	A1
Wide range RCS hot temperature	40°F to 700°F	4	PAM Type B T-2, T-3, and T-5 interlocks Degrees of subcooling MCR indication Plant historian	Top of downcomer	A1
Narrow range RCS cold temperature	400°F to 650°F	8	NSSS control MCR indication Plant historian Input to calorimetric calculation	Downcomer below feedwater inlets	B2
Wide range RCS cold temperature	40°F to 700°F	4	LTOP T-1 interlock MCR indication Plant historian	Downcomer below feedwater inlets	A2
PZR liquid temperature	40°F to 800°F	2	NSSS control MCR indication Plant historian	Lower PZR	B2
PZR vapor temperature	40°F to 800°F	2	NSSS control MCR indication Plant historian	Upper PZR	B2

Temperature Sensors	Range	Quantity	Function	Location	Safety and Risk Classification
CNV air temperature	40°F to 600°F	2	NSSS control MCR indication Plant historian	Upper part of containment	B2
Main steam temperature (DHR inlet temperature)	100°F to 700°F	8	RTS ESFAS PAM Type D Input to calorimetric calculation MCR indication NSSS control Plant historian	Upstream of main steam isolation valve (MSIV) on MS pipe	A1
Feedwater temperature	40°F to 440°F	6	NSSS control MCR indication Input to calorimetric calculation Plant historian	Upstream of feedwater isolation valve (FWIV) on feedwater (FW) pipe	B2
DHRS outlet temperature	40°F to 440°F	4	PAM Type D MCR indication Plant historian	Bottom of DHRS unit	B2
Under-the-bioshield temperature	40°F to 700°F	4	RTS ESFAS PAM Type D MCR indication Plant historian	Under the bioshield	A1

4.1 Narrow Range Reactor Coolant System Hot Temperature

4.1.1 Sensor Functions

The primary function of the narrow range reactor coolant system (RCS) hot temperature sensors is to provide temperature measurements for the reactor trip, engineered safeguards features actuation system (ESFAS) actuation, and NSSS control functions. To obtain an accurate indication, multiple sensors are required. By taking multiple temperature measurements at several locations in the quadrant and averaging them, an accurate measurement is achievable. The averaging process is expected to compensate for any streaming effects that may be present at the top of the RPV riser.

Safety-related functions are implemented by the MPS. Nonsafety-related functions are implemented in MCS using an isolated signal output from MPS rather than a direct connection to the sensors. Narrow range RCS hot temperature functions are listed in Table 4-1.

4.1.2 Sensor Requirements

Safety classification: A1

Seismic classification: Category I

Range: 400 to 650 degrees Fahrenheit

Sensor accuracy: ± {{ }}2(a),(c) degrees Fahrenheit

Sensor response time: $\leq$ 6 seconds

Quantity: twelve (four separation groups of three sensors each)

4.1.3 Sensor Description

Three narrow range RCS hot temperature RTDs signals per quadrant are sent to the module protection system (MPS) which implements signal conditioning algorithms to determine an average temperature value for each quadrant. An average temperature signal is preferable to a single signal to compensate for the temperature streaming effects in the RCS flow.

4.1.3.1 Location

The RTDs are located in thermowells that intersect the reactor coolant flow path, below the pressurizer baffle plate, and upstream of the helical coil section of the tube bundles of the steam generators. These thermowell inserts are located in quadrants that form separation groups around the pressure vessel. The RTDs are not directly exposed to the RPV environment as they are mounted in thermowells. However, they will need to be conservatively qualified for the containment environment.

4.1.3.2 Installation

The sensors are installed in thermowells on the RPV vessel and inside containment. The RTD signals are routed through containment with MI cabling so that the signals can withstand normal and design basis event (DBE) environments.

A total of twelve sensing elements, three per separation group, are planned. They are mounted below the pressurizer baffle plate section to obtain safety-related narrow range RCS hot temperature measurement. For this configuration, one of the three narrow range RTDs share a thermowell with the wide range RTD as a dual element wide range (WR) or narrow range (NR) RTD in each quadrant to minimize the number of thermowell installations in the vessel.

The precise RTD location within the quarter section of RPV and the depth of the RTD extension into the RPV annulus has not yet been determined. In depth flow analysis with modelled temperature streaming will be evaluated for this determination, and is captured in the future work section below.

4.1.3.3 Maintenance

The temperature elements are mounted and cables routed such that maintenance can be performed. The sensors are accessible while the module is in the refueling bay dry dock and have the ability to be maintained, removed, and reinstalled.

An RTD cross calibration is required before or after the refueling outage. The calibration requires access to the MPS cabinets and an RTD cross calibration test set. An in-situ function test is also being planned for post-dry dock testing after the vessel has been moved back to its operating bay.

The RTD cross calibration is performed in accordance with procedures in the licensee’s maintenance program and the plant technical specifications. The method for performing the RTD cross calibration for the NuScale design is similar to those used in other designs. The RTD resistance measurements are compared to each other and traced to laboratory calibration data at various temperatures during plant heat-up and cool-down. Acceptance criteria are determined based on vendor specifications for the RTDs and the plant safety analysis. The test acceptance criteria specify a limit within which no action is required, a limit within which a new calibration curve can then be determined for the RTD based on measured data, and a limit which requires the RTD to be declared inoperable and repaired or replaced.

4.1.3.4 Qualification

The RTDs and respective cables will be conservatively qualified to operate in the containment normal conditions and DBE conditions in accordance with industry standards.

4.1.4 Future Work

1. {{

}}2(a),(b)

4.2 Wide Range Reactor Coolant System Hot Temperature

4.2.1 Sensor Functions

The primary function of the wide range RCS hot temperature measurement is to provide the full range temperature monitoring for PAM and operator display.

Safety-related functions are implemented by the MPS. Nonsafety-related functions are implemented in MCS using an isolated signal output from MPS rather than a direct connection to the sensors. Wide range RCS hot temperature functions are listed in Table 4-1.

4.2.2 Sensor Requirements

Safety classification: A1

Seismic classification: Category I

Range: 40 to 700 degrees Fahrenheit

Sensor accuracy: ± {{ }}2(a),(c) degrees Fahrenheit

Sensor response time: $\leq$ 6 seconds

Quantity: Four RTDs (one per quadrant)

4.2.3 Sensor Description

The wide range RCS hot temperature RTDs have a range of measurement from 40 degrees Fahrenheit to 700 degrees Fahrenheit and are installed in thermowells shared with one narrow range RTD per quadrant. The RTD leads are routed from the sensor up to the containment head, through the electrical penetration assemblies (EPAs) on the CNV head, and then to the MPS electronics cabinets.

4.2.3.1 Location

The RTDs are located in thermowells that intersect the reactor coolant flow path, below the pressurizer baffle plate and upstream of the steam generators. These thermowell inserts are located in quadrants that form separation groups around the pressure vessel. The RTDs themselves are not exposed to the RPV environment, but will be conservatively qualified for the containment environment.

4.2.3.2 Installation

Four RTDs total, with one per separation group, are installed in thermowells below the pressurizer baffle plate section to obtain the temperature measurement. These RTDs are installed in thermowells on the containment side of the RPV and will be conservatively qualified to operate in the containment normal and DBE environments. For this configuration the wide range RTD shares a thermowell with one of the narrow range RCS hot temperature RTDs (as a dual element WR and NR RTD) in each quadrant to minimize the number of thermowell installations in the vessel. These RTDs measure the reactor coolant temperature through the thermowell. The RTD signals are routed through containment with MI cabling so that the signals can withstand normal and DBE environments.

4.2.3.3 Maintenance

The temperature elements are mounted and cables are routed such that maintenance can be performed. The sensors are accessible while the module is in the refueling bay dry dock and have the ability to be maintained, removed, and reinstalled.

An RTD cross calibration is required before or after the refueling outage. The calibration requires access to the MPS cabinet and an RTD cross calibration test set. An in-situ RTD test is also performed to ensure functionality of the RTD after the move back to the reactor pool. The cross-calibration will be performed as described in Section 4.1.3.3.

4.2.3.4 Qualification

The RTDs and respective cables will be conservatively qualified to operate in the containment normal conditions and DBE conditions in accordance with industry standards.

4.2.4 Future Work

1. {{

}}2(a),(b)

3. {{

}}2(a),(b)

4.3 Narrow Range Reactor Coolant System Cold Temperature

4.3.1 Sensor Functions

The primary functions of the narrow range RCS cold temperature sensors are to acquire temperature measurements for MCR indication, primary side calorimetric calculations, and to compute the average temperature calculation for NSSS control functions. The narrow range RTD signals require multiple sensors to adequately acquire the average temperature. The reactor coolant is expected to be well mixed after passing though the steam generators; however, there may still be thermal streaming effects. An averaging scheme compensates for those effects.

Narrow range RCS cold temperature functions are listed in Table 4-1.

4.3.2 Sensor Requirements

Safety classification: B2

Seismic classification: Category II

Range: 400 to 650 degrees Fahrenheit

Sensor accuracy: ± {{ }}2(a),(c) degrees Fahrenheit

Sensor response time: $\leq$ 6 seconds

Quantity: Eight (four channels of two sensors each)

4.3.3 Sensor Description

Two narrow range RTD signals per RPV quadrant are sent to the MCS which implements signal conditioning algorithms to determine an average temperature value for each quadrant. An average temperature signal is preferable to a single temperature signal to compensate for temperature streaming effects in the RCS.

4.3.3.1 Location

The narrow range RTDs are located in thermowells on the side of the RPV in the lower downcomer region near the ultrasonic flow sensors. These thermowell inserts are located in quadrants around the pressure vessel in the lower downcomer region. The thermowells are the pressure boundary between the RPV and CNV environments. The RTDs are not exposed to the RPV environment, but will be conservatively qualified for the containment environment. The RTD leads are routed up to the containment head using MI cable, through the EPAs on the CNV head, and then to the MCS electronics cabinets.

4.3.3.2 Installation

Eight RTDs, two per channel, are mounted in thermowells below the steam generators. The RTD leads are routed to the EPAs on the containment head. From there, the RTD cables are routed to the MCS electronics cabinets located in a mild environment. For this configuration one of the two narrow range RTDs share a thermowell with the wide range RTD (dual element WR and NR RTD) in each quadrant to minimize the number of thermowell installations in the vessel.

4.3.3.3 Maintenance

The temperature elements are mounted and cables are routed such that maintenance can be performed. The RTDs are accessible while the module is in the refueling bay dry dock, and have the ability to be maintained, removed, and reinstalled. Their location on the exposed area between the CNV flange and the RPV flange allows for RTD removal or replacement, while in the refueling bay dry dock.

An RTD cross calibration is required before or after the refueling outage. The calibration requires access to the MPS cabinet and an RTD cross calibration test set. An in-situ RTD test is also performed to ensure functionality of the RTD after the move back to the reactor pool. The cross-calibration will be performed as described in Section 4.1.3.3.

4.3.3.4 Qualification

The narrow range RCS cold temperature RTDs and respective cables are designed for operability in the containment pressure vessel normal environment.

4.3.4 Future Work

1. {{

}}2(a),(b)

5. {{

}}2(a),(b)

4.4 Wide Range Reactor Coolant System Cold Temperature

4.4.1 Sensor Functions

The primary function of the wide range RCS cold temperature measurement is to provide the full range temperature monitoring for LTOP and operator display.

Wide range RCS cold temperature functions are listed in Table 4-1.

4.4.2 Sensor Requirements

Safety classification: A2

Seismic classification: Category I

Range: 40 to 700 degrees Fahrenheit

Sensor accuracy: ± {{ }}2(a),(c) degrees Fahrenheit

Sensor response time: ≤ 6 seconds

Quantity: Four temperature sensors (one per quadrant)

4.4.3 Sensor Description

The wide range RCS cold temperature RTDs provide the temperature input for the low-temperature over-pressure protection logic.

4.4.3.1 Location

The wide range RTDs are located in thermowells located in the lower downcomer of the RPV, downstream of the steam generators.

4.4.3.2 Installation

The wide range RTD shares a thermowell with one of the narrow range RTDs (as a dual element WR or NR RTD) in each quadrant to minimize the number of thermowell installations in the vessel. The RTD lead wires are routed through a support conduit to the CNV penetration assemblies. The RTD signals are routed through containment with MI cabling so that the signals can withstand normal and DBE environments.

4.4.3.3 Maintenance

The RTDs are mounted and cables are routed such that maintenance can be performed. The sensors are accessible while the module is in the refueling bay dry dock and have the ability to be maintained, removed, and reinstalled. Their location on the exposed area between the CNV flange and the RPV flange allow for RTD removal or replacement, while in the refueling bay dry dock.

An RTD cross calibration is required before or after the refueling outage. The calibration requires access to the MPS cabinet and an RTD cross calibration test set. An in-situ RTD test is also performed to ensure functionality of the RTD after the move back to the reactor pool. The cross calibration will be performed as described in Section 4.1.3.3.

4.4.3.4 Qualification

The LTOP function of these RTDs requires the RTDs to meet the harsh environment qualification requirements for the containment environment.

4.4.4 Future Work

1. {{

}}2(a),(b)

4.5 Pressurizer Liquid Temperature

4.5.1 Sensor Functions

The primary function of the pressurizer temperature measurement is to provide pressurizer liquid temperature information for operator display and NSSS (start-up and shutdown) control.

Pressurizer liquid temperature measurement functions are listed in Table 4-1.

4.5.2 Sensor Requirements

Safety classification: B2

Seismic classification: Category II

Range: 40 to 800 degrees Fahrenheit

Sensor accuracy: ± {{ }}2(a),(c) degrees Fahrenheit

Sensor response time: $\leq$ 6 seconds

Quantity: Two temperature sensors

4.5.3 Sensor Description

The pressurizer liquid temperature measurement provides indication to the MCR and plant historian for operational actions during start-up and shutdown.

4.5.3.1 Location

The pressurizer liquid temperature RTDs are located in thermowells above the pressurizer baffle plate and below the normal operating liquid level. These thermowell inserts are located in opposite quadrants around the pressurizer section of the RPV.

4.5.3.2 Installation

The RTDs are mounted in thermowells in the lower section of the pressurizer. The RTD cabling is MI cable to protect the electronic signal from the containment environment conditions. The wiring is routed from the RTD in the thermowell location to the designated containment vessel EPAs and then to the MCS cabinets located in a mild environment outside containment.

4.5.3.3 Maintenance

The temperature elements are mounted and cables are routed such that maintenance can be performed. The RTDs and associated cabling have the ability to be removed and replaced while in dry dock during a refueling outage.

4.5.3.4 Qualification

The pressurizer liquid temperature RTDs and respective cables will be designed to operate in containment normal operating conditions.

4.5.4 Future Work

1. {{

}}2(a),(b)

5. {{

}}2(a),(b)

4.6 Pressurizer Vapor Temperature

4.6.1 Sensor Functions

The primary function of the pressurizer vapor temperature sensor is to provide indication for operator display. This display is intended for operator use mainly during start up and shutdown operations. It also provides indication to the plant historian.

Pressurizer vapor temperature measurement functions are listed in Table 4-1.

4.6.2 Sensor Requirements

Safety classification: B2

Seismic classification: Category II

Range: 40 to 800 degrees Fahrenheit

Sensor accuracy: ± {{ }}2(a),(c) degrees Fahrenheit

Sensor response time: $\leq$ 6 seconds

Quantity: Two temperature sensors.

4.6.3 Sensor Description

The pressurizer vapor temperature measurement provides indication to the MCR and plant historian for operational actions during start up and shutdown. These RTDs are inserted into thermowells to ensure RPV pressure boundary conditions are met.

4.6.3.1 Location

The pressurizer vapor temperature RTDs are located in thermowells near the top of the RPV to measure the vapor temperature of the pressurizer bubble. These thermowell inserts are located in opposite quadrants around the pressurizer section of the RPV.

4.6.3.2 Installation

The two RTDs are installed in thermowells in the vapor section of the pressurizer. The RTD signals are protected from the containment environment by MI cables. The cabling is routed from the RTD in the thermowell location to the designated containment vessel EPAs, and then to the MCS cabinets located in a mild environment outside containment.

4.6.3.3 Maintenance

The temperature elements are mounted and cables are routed such that maintenance can be performed. The RTDs are accessible and retrievable for necessary maintenance or replacement. The sensors and associated cabling have the ability to be removed and replaced while in dry dock during a refueling outage. The calibration methodology for these sensors is an item for the Future Work section below.

4.6.3.4 Qualification

The pressurizer vapor temperature RTDs and respective cables will be designed to operate in containment normal operating conditions.

4.6.4 Future Work

See Section 4.5.4 for the Future Work items associated with this sensor function.

4.7 Containment Air Temperature

4.7.1 Sensor Functions

The primary function of the containment air temperature sensor is to provide general containment atmospheric temperature for operator display. It also provides indication to the plant historian and is available for NSSS control functions.

Containment air temperature measurement functions are listed in Table 4-1.

4.7.2 Sensor Requirements

Safety classification: B2

Seismic classification: Category II

Range: 40 to 600 degrees Fahrenheit

Sensor accuracy: ± {{ }}[2(a),(c)] degrees Fahrenheit

Sensor response time: $\leq$ 6 seconds

Quantity: Two temperature sensors

4.7.3 Sensor Description

The containment air temperature measurement provides indication to the MCR and plant historian for operational and trending purposes. These RTDs are expected to perform this measurement through mountings located on the inside of containment located in the upper part of containment. These RTDs do not perform a safety function, but will be designed to operate in the normal containment environment.

4.7.3.1 Location

The containment air temperature RTDs are located on mountings on the inside of containment, near the top of the CNV to measure the air or vacuum temperature of the containment atmosphere. The mountings are positioned away from high-energy line break intensity areas.

4.7.3.2 Installation

The two RTDs are installed on mountings near the top inside of containment. They are not housed in a thermowell, but are mounted such that the temperature sensing can occur in the environment in which the RTD element resides. The RTD electrical leads are routed through the EPAs and then to the MCS electronics cabinets located in a mild environment.

4.7.3.3 Maintenance

The temperature elements are mounted and cables are routed such that maintenance can be performed while in the refueling bay dry dock. The RTDs are accessible, and retrievable for necessary maintenance and replacement. The sensors and associated cabling have the ability to be removed and replaced during a refueling outage.

4.7.3.4 Qualification

The containment air temperature RTDs and respective cables will be designed to operate in normal containment conditions.

4.7.4 Future Work

1. {{

}}2(a),(b)

4.8 Main Steam Temperature

4.8.1 Sensor Functions

The primary purpose of the main steam (MS) temperature sensor is to determine MS superheat for RTS and ESFAS actuations. This sensor is also required for MCR indication, calorimetric calculation of reactor power, and NSSS control. The MS temperature measurement also serves as the DHRS inlet temperature measurement.

Safety-related functions are implemented by the MPS. Nonsafety-related functions are implemented in MCS using an isolated signal output from MPS rather than a direct connection to the sensors. MS temperature measurement functions are listed in Table 4-1.

4.8.2 Sensor Requirements

Safety classification: A1

Seismic classification: Category I

Range: 100 to 700 degrees Fahrenheit

Sensor accuracy: ± {{ }}2(a),(c) degrees Fahrenheit

Sensor response time: $\leq$ 6 seconds

Quantity: Eight (four RTDs per MS pipe, two MS pipes)

4.8.3 Sensor Description

The concept for the MS temperature measurement is to use RTDs inserted in thermowells in the MS pipe sections on the upstream side of the MSIVs outside containment. Because the application is a pipe structure, conventional technology can be implemented. There are two MS pipes exiting containment with four thermowells per pipe. The eight sensing elements are routed to the four MPS separation groups in the MPS for calculation of steam superheat. The RTDs are made to fit in the thermowells, but otherwise the device is commercially available.

4.8.3.1 Location

The location of the RTDs is in thermowells, outside of containment, underneath the bioshield, in the pipe section upstream of the MSIVs.

4.8.3.2 Installation

The RTDs are installed in thermowells in the pipe section above the reactor pool level and underneath the bioshield. Conventional installation processes can be adapted for the location.

4.8.3.3 Maintenance

The temperature elements are mounted and cables are routed such that maintenance can be performed. The RTDs are accessible and retrievable for necessary maintenance or replacement. The sensors and associated cabling have the ability to be retracted, relocated, or removed during refueling and the ability can be reinstalled when refueling is complete.

4.8.3.4 Qualification

The main steam RTDs and respective cables will be tailored for fit, with a qualification that envelopes the under-the-bioshield normal and DBE environment.

4.8.4 Future Work

1. {{

}}2(a),(b)

4.9 Feedwater Temperature

4.9.1 Sensor Functions

The primary purpose of the feedwater temperature sensors is to determine feedwater temperature for indication in the MCR and for NSSS controls. This sensor is also required for plant historian and calorimetric calculations.

Feedwater temperature measurement functions are listed in Table 4-1.

4.9.2 Sensor Requirements

Safety classification: B2

Seismic classification: Category II

Range: 40 to 440 degrees Fahrenheit

Sensor accuracy: ± {{ }}2(a),(c) degrees Fahrenheit

Sensor response time: $\leq$ 6 seconds

Quantity: Six (three RTDs per FW pipe, two FW pipes)

4.9.3 Sensor Description

The concept for the measurement of feedwater temperature is with RTDs in thermowells. Because the location of the device is outside of containment, the use of conventional means of temperature measurement is desired. An RTD of similar accuracy to the MS temperature sensors allows for similar accuracy when computing steam-feed delta temperature. There are two feedwater pipes going into containment and three feedwater RTDs on each pipe. A configuration of three sensors per pipe allows for the median select approach for NSSS control purposes.

The RTDs themselves can be made to fit in the thermowells, but otherwise the device is commercially available.

4.9.3.1 Location

The location of these RTDs is underneath the bioshield, on the upstream side of the FWIVs, and downstream of the feedwater separation flange. There will be three RTDs on each feedwater inlet pipe.

4.9.3.2 Installation

The RTDs are installed in thermowells in the FW pipe section above the reactor pool level and under-the-bioshield. Conventional installation processes can be adapted for the location.

4.9.3.3 Maintenance

The temperature elements are mounted and cables are routed such that maintenance can be performed. The sensors and associated cabling have the ability to be retracted, relocated, or removed during refueling, and the ability to be reinstalled when refueling is complete.

4.9.3.4 Qualification

The feedwater temperature RTDs, although not safety-related, will be designed to operate in the normal under-the-bioshield environment. The RTDs are developed and will be tested to environmental parameters that envelope this environment. These RTDs are expected to be commercially available with tailoring for fit.

4.9.4 Future Work

1. {{

}}2(a),(b)

4.10 Decay Heat Removal System Outlet Temperature

4.10.1 Sensor Functions

The primary purpose of the DHRS outlet temperature sensors is to monitor DHRS temperature for indication in the MCR and for PAM Type D variable indication.

DHRS temperature measurement functions are listed in Table 4-1.

4.10.2 Sensor Requirements

Safety classification: B2

Seismic classification: Category I

Range: 40 to 440 degrees Fahrenheit

Sensor accuracy: ± {{ }}2(a),(c) degrees Fahrenheit

Sensor response time: ≤ 6 seconds

Quantity: Four (two RTDs per DHRS condenser)

4.10.3 Sensor Description

The concept for the measurement of DHRS outlet temperature is with RTDs in thermowells. Because the locations of the devices are outside of containment, the use of conventional temperature measurement is desired. The RTDs must be waterproof and submergible to work in the submerged DHRS condenser.

The RTDs can be made to fit in the thermowells. Because of the PAM function, they must be qualified to the environment in which they are located.

In certain DBE scenarios, when feedwater is isolated, the DHRS outlet RTDs give indication of steam generator inlet temperature.

4.10.3.1 Location

There will be two RTD sensors per DHRS condenser, one per division on each DHRS condenser to support the PAM Type D variable function. These RTDs are located in the bottom piping of the DHRS condenser.

4.10.3.2 Installation

The RTDs are installed in thermowells in the lower condenser section outside of containment, in the pool. Conventional installation processes can be adapted for the location.

4.10.3.3 Maintenance

The temperature elements are mounted and cables are routed such that maintenance can be performed. The sensors and associated cabling have the ability to be retracted, relocated, or removed during refueling, and the ability to be reinstalled when refueling is complete.

4.10.3.4 Qualification

The PAM function of the DHRS outlet temperature requires that the RTDs be qualified to operate in the pool environment. These RTDs are expected to be commercially available with tailoring for fit.

4.10.4 Future Work

1. {{

}}2(a),(b)

4.11 Under-the-Bioshield Temperature

4.11.1 Sensor Functions

The primary function of the under-the-bioshield temperature sensors is to provide under-the-bioshield temperature measurements for RTS and ESFAS functions. These sensors also provide temperature indication as a PAM Type D variable and provide indication to the MCR.

Safety-related functions are implemented by the MPS. Nonsafety-related functions are implemented in MCS using an isolated signal output from MPS rather than a direct connection to the sensors. Under-the-bioshield temperature functions are listed in Table 4-1.

4.11.2 Sensor Requirements

Safety classification: A1

Seismic classification: Category I

Range: 40 to 700 degrees Fahrenheit

Sensor accuracy: ± {{ }}2(a),(c) degrees Fahrenheit

Sensor response time: ≤ 6 seconds

Quantity: Four (one for each separation group)

4.11.3 Sensor Description

The concept for the under-the-bioshield temperature measurement is to use harsh environment qualified RTDs mounted underneath the bioshield. These RTDs do not need a thermowell as they are mounted in the environment in which they are sensing. The RTDs may be the same quality RTDs being used for safety system actuations inside containment as the qualification profiles are similar. The four sensing elements are routed to the four MPS separation groups in the MPS for under-the-bioshield environment based actuation.

4.11.3.1 Location

The location of the RTDs is outside of containment, underneath the bioshield, on the reactor pool wall.

4.11.3.2 Installation

The RTDs are mounted on the reactor pool wall underneath the bioshield. Cabling from the RTDs is routed to the disconnect panel on the pool wall. Conventional installation processes can be adapted for the location.

4.11.3.3 Maintenance

The temperature elements are mounted and cables are routed such that maintenance can be performed. The RTDs are accessible and retrievable for maintenance or replacement.

4.11.3.4 Qualification

The {{

}}2(a),(c)

4.11.4 Future Work

1. {{

}}2(a),(b)

5.0 Pressure Measurement in the NPM

NuScale initiated a Phase I pressure study whose purpose was to develop conceptual designs for pressure measurement that meet the requirements of the NPM. The scope of the study was to investigate and develop approaches for measuring the following:

1. Pressurizer pressure
2. Wide range RCS pressure
3. Narrow range containment pressure
4. Wide range containment pressure
5. MS pressure
6. Feedwater and DHRS outlet pressure

Background

A Phase I contract was issued to develop and present conceptual designs for pressure measurement that meet the requirements of the NPM. The pressure-sensing instrumentation ranges are shown in Table 5-1.

Inside Containment Pressure Sensors

Several concepts for practical approaches to measuring pressure in the NPM were presented in the Phase 1 study that used readily available technologies and products. The inside containment options {{

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

{{

}}2(a),(c),ECI radiation hardened and temperature tolerant pressure transducer mounted inside containment with remote electronics approach for in pressure sensors located in containment.

The development of the pressure transducer has two approaches, one with remote analog electronics and one with remote digital processing electronics. This sensor equipment diversity is required to meet the equipment assumptions of the NuScale diversity and defense in depth analysis for the MPS.

Outside Containment Pressure Sensors

The pressure sensors located outside of containment, MS pressure and feedwater pressure, use conventional transmitter technology combined with a re-qualification of the transmitters to envelope the current environment for the respective areas.

Alternate pressure measuring approaches as described in section 2.4, were evaluated, and not chosen. These technologies remain as back-ups for the current baseline design.

Table 5-1 Pressure Sensor List

Pressure Sensors	Range (psia)	Quantity	Function	Location	Safety and Risk Classification
Pressurizer pressure	1500 to 2200	4	RTS ESFAS NSSS control MCR indication Plant historian	Near top of PZR in CNV	A1
Wide range RCS pressure	0 to 2500	4	LTOP PAM Type B, C, and D Degrees of subcooling NSSS control MCR indication Plant historian	Near top of PZR in CNV	A2

Pressure Sensors	Range (psia)	Quantity	Function	Location	Safety and Risk Classification
Narrow range containment pressure	0 to 20	4	RTS ESFAS PAM Type B NSSS control MCR indication Plant historian	Upper part of CNV	A1
Wide range containment pressure	0 to 1200	2	PAM Type B, C, and D MCR indication Plant historian	Upper part of CNV	B2
Main steam pressure (DHR inlet pressure)	0 to 1200	8	RTS ESFAS PAM Type D MCR indication NSSS control Plant historian Input to calorimetric calculation	Upstream of MSIVs on DHRS tee	A1
Feedwater pressure and DHRS outlet pressure	0 to 1200	6	PAM Type D MCR indication Plant historian NSSS control Input to calorimetric calculation	Bottom of DHRS unit	B2

5.1 Pressurizer Pressure

5.1.1 Sensor Functions

Pressurizer pressure signals are used to monitor RCS pressure and to generate appropriate indications, alarms, reactor trips, or ESFAS actuation functions when required. Isolated output signals are also provided to the MCS for non-safety control and indication functions.

Safety-related functions are implemented by the MPS. Nonsafety-related functions are implemented in MCS using an isolated signal from MPS rather than a direct connection to the sensors. Pressurizer pressure functions are listed in Table 5-1.

5.1.2 Sensor Requirements

Safety classification: A1

Seismic classification: Category I

Range: 1500 to 2200 pounds per square inch absolute (psia)

Sensor accuracy: ± {{ }}2(a),(c) percent of calibrated span

Sensor Response time: $\leq$ 0.4 seconds

Quantity: Four (one for each separation group)

5.1.3 Sensor Description

The pressure transducer with remote electronics, which is described in section 5.0, was selected for the baseline pressurizer pressure sensor. The primary reason for this choice was its increased temperature and radiation survivability compared to conventional pressure transmitters. This sensor concept has the radiation and temperature tolerant transducer in containment with the conditioning and processing electronics located in a milder environment outside containment.

Four pressure transducers are located in containment and sense the pressure in the pressurizer through sensing lines. The transducers convert the pressure signal to an electronic signal. The electronic signal passes through the containment EPAs to be processed by remote digital electronics outside containment.

5.1.3.1 Location

The pressurizer pressure transducer is located close to its sensing line taps near the top of the pressurizer section of the RPV. The remote processing electronics are located in a mild environment outside containment.

5.1.3.2 Installation

The pressure-sensing taps open to sensing lines that connect to the pressure transducer. The pressure transducer is installed on a mounting in the containment annulus. These sensing lines are designed in accordance with Reference 9.1.1. The signal is routed out of containment using MI cable and through the containment penetrations. From there, the signal goes to the processing electronics cabinets located in a mild environment.

5.1.3.3 Maintenance

During refueling outages, the transducer and the associated electronics can be accessed for calibration and possible replacement. The power supplies are housed in the processing cabinets in a mild environment and some routine power supply maintenance is expected.

5.1.3.4 Qualification

NuScale environmental requirements are the prevailing criteria for sensor qualification. The transducer and the corresponding remote electronics are specified to meet the requirements of the harsh environment qualification standards for the appropriate NuScale environments.

5.1.4 Future Work

1. {{

}}2(a),(b)

5.2 Wide Range Reactor Coolant System Pressure

5.2.1 Sensor Functions

The primary function of the wide range RCS pressure measurement is to provide pressure indication for PAM and LTOP.

Safety-related functions are implemented by the MPS. Nonsafety-related functions are implemented in MCS using an isolated signal output from MPS rather than a direct connection to the sensors. Wide range RCS pressure functions are listed in Table 5-1.

5.2.2 Sensor Requirements

Safety classification: A2

Seismic classification: Category I

Range: 0 to 2500 psia

Sensor accuracy: ± {{ }}2(a),(c) percent of calibrated span

Sensor response time: $\leq$ 0.4 seconds

Quantity: Four (one for each separation group)

5.2.3 Sensor Description

The pressure transducer with remote electronics, which is described in section 5.0, was selected for the wide range RCS pressure sensor. The primary reason for this choice was its increased temperature and radiation survivability compared to conventional pressure transmitters. This sensor concept has the radiation and temperature tolerant transducer in containment with the conditioning and processing electronics located in a milder environment outside containment.

Four pressure transducers are located in containment and sense the pressure in the RPV through sensing lines. The transducers convert the pressure signal to an electronic signal. The electronic signal passes through the containment EPAs to be processed by remote digital electronics outside containment and provide a signal to the MPS.

5.2.3.1 Location

The wide range RCS pressure transducers are located close to the narrow range pressure transducers at the top of the pressurizer section of the RPV. The remote processing electronics are located in a mild environment outside containment.

5.2.3.2 Installation

The pressure transducer is installed on a mounting in containment and will measure RCS pressure using sensing lines. These sensing lines are designed in accordance with Reference 9.1.1. The signal is routed using MI cable through the containment penetrations, out of containment to the conditioning and processing electronics.

5.2.3.3 Maintenance

During refueling outages, the transducer and the associated electronics can be accessed for calibration and possible replacement. The power supplies are housed in the processing cabinets in a mild environment, and some routine power supply maintenance is expected.

5.2.3.4 Qualification

NuScale environmental requirements are the prevailing criteria for sensor qualification. The transducer and the corresponding remote electronics are specified to meet the requirements of the environmental qualification standards for the appropriate NuScale environments.

5.2.4 Future Work

See Section 5.1.4 for the Future Work items associated with this sensor function.

5.3 Narrow Range Containment Pressure

5.3.1 Sensor Functions

The primary function of the narrow range containment pressure sensor is to provide an accurate measurement of containment pressure for reactor trip and ESFAS actuations. The narrow range containment pressure is scaled to measure in a narrow band around expected operating pressures with margin. Narrow range containment pressure is also used to supply main control room alarms, control room displays, and plant historian.

Safety-related functions are implemented by the MPS. Nonsafety-related functions are implemented in MCS using an isolated signal output from MPS rather than a direct connection to the sensors. Narrow range containment pressure functions are listed in Table 5-1.

5.3.2 Sensor Requirements

Safety classification: A1

Seismic classification: Category I

Range: 0 to 20 psia

Sensor accuracy: ± {{ }}2(a),(c) percent of calibrated span

Sensor response time: $\leq$ 0.4 seconds

Quantity: Four, (one for each separation group)

5.3.3 Sensor Description

The pressure transducer with remote electronics, which is described in section 5.0, was selected for the narrow range containment pressure sensor. The primary reason for this choice was its increased temperature and radiation survivability compared to conventional pressure transmitters. This sensor concept has the radiation and temperature tolerant transducer in containment with the conditioning and processing electronics located in a milder environment outside containment.

Four pressure transducers are located in containment to sense the pressure in the environment in which they are located. The transducers sense the pressure and convert the pressure signal to an electronic signal. The electronic signal passes through the containment EPAs to be processed by remote electronics outside containment and provide a signal to the MPS.

This sensor configuration differs slightly from the other pressure transducers with remote electronics in that it is processing an analog signal instead of a digital signal. The use of analog equipment was specified for this sensor function to provide equipment diversity commensurate with the assumptions in the NuScale diversity and defense in depth analysis for the MPS.

5.3.3.1 Location

The narrow range pressure transducers are located inside, near the top of containment. This location is chosen for reducing cable length and ease of access and mounting. The remote processing electronics are located in a mild environment outside containment.

5.3.3.2 Installation

Four narrow range pressure transducers, one for each separation group, are installed in containment in four different locations, supplying four different separation groups. Each pressure transducer senses the pressure environment in which it is located. The transducers are located in a place that allows them to be maintained and replaced during refueling outages. The pressure signal is routed on MI cables, through the containment penetration, to the analog sensor processing electronics, and then to the MPS system.

5.3.3.3 Maintenance

During refueling outages, the transducers can be accessed for calibration and possible replacement. The power supplies for the sensor are housed in processing cabinets. Some routine power supply maintenance is expected.

5.3.3.4 Qualification

NuScale environmental requirements are the prevailing criteria for sensor qualification. The transducer and the corresponding remote electronics are specified to meet the requirements of the environment qualification standards for the appropriate NuScale environments.

5.3.4 Future Work

1. {{

}}2(a),(b)

5.4 Wide Range Containment Pressure

5.4.1 Sensor Functions

The primary function of the wide range containment pressure sensor is to provide pressure measurement for post-accident monitoring. Wide range containment pressure is also used to supply main control room alarms, control room displays, and plant historian.

Wide range containment pressure functions are listed in Table 5-1.

5.4.2 Sensor Requirements

Safety classification: B2

Seismic classification: Category I

Range: 0 to 1200 psia

Sensor accuracy: ± {{ }}$^{2(a),(c)}$ percent of calibrated span

Sensor response time: $\leq$ 0.4 seconds

Quantity: Two, (one for each division, routed to separation groups B and C)

5.4.3 Sensor Description

The pressure transducer with remote electronics, which is described in section 5.0, was selected for the wide range containment pressure sensor. The primary reason for this choice was its increased temperature and radiation survivability compared to conventional pressure transmitters. This sensor concept has the radiation and temperature tolerant transducer in containment with the conditioning and processing electronics located in a milder environment outside containment.

This sensing concept calls for two transducers located inside, near the top of containment. These transducers sense the pressure in the environment that they are in and convert the pressure signal to an electronic signal. The electronic signal passes through the containment EPAs to be processed by remote digital electronics outside containment.

5.4.3.1 Location

The wide range containment pressure transducers are located inside containment, near the top of containment. This location is chosen for reducing cable length and ease of access and mounting. The processing electronics are located in a mild environment outside of containment.

5.4.3.2 Installation

Two wide range pressure transducers are installed in containment in two locations and cables are routed through separation groups B and C penetration assemblies. Each pressure transducer senses the pressure environment in containment. The transmitters are located in a place that allows them to be maintained and replaced during refueling outages. The pressure signal is routed on MI cables, through the containment penetrations, to the sensor processing electronics, and then to the MPS system for processing.

5.4.3.3 Maintenance

During refueling outages, the transducers can be accessed for calibration and possible replacement. The power supplies for the sensor are housed in processing cabinets. Some routine power supply maintenance is expected.

5.4.3.4 Qualification

NuScale environmental requirements are the prevailing criteria for sensor qualification. The transducer and the corresponding remote electronics are specified to meet the requirements of the harsh environment qualification standards for the appropriate NuScale environments. Because this pressure sensor has a PAM Type B and C variable function, its qualification requirement includes both normal and DBE containment environments.

5.4.4 Future Work

See Section 5.3.4 for the Future Work items associated with this sensor function.

5.5 Main Steam Pressure

5.5.1 Sensor Functions

The primary function of the main steam (MS) pressure sensor is to measure main steam pressure as close to the SG steam plenum as possible with the intent of attaining a highly accurate steam pressure measurement for protection system purposes. This measurement is used for RTS and ESFAS actuations, PAM Type D variable function, NSSS controls, and MCR indication.

Note: MS pressure also serves as DHRS inlet pressure, when DHRS valves are actuated.

Safety-related functions are implemented by the MPS. Nonsafety-related functions are implemented in MCS using an isolated signal output from MPS rather than an direct connection to the sensors. Main steam pressure functions are listed in Table 5-1.

5.5.2 Sensor Requirements

Safety classification: A1

Seismic classification: Category I

Range: 0 to 1200 psia

Sensor accuracy: ± {{ }}2(a),(c) percent of calibrated span

Sensor response time: ≤ 0.5 seconds

Quantity: Eight (two per DHRS pipe, two pipes per DHRS train)

5.5.3 Sensor Description

The MS pressure sensors will use existing technology and conventional nuclear steam pressure transmitters. Numerous vendors manufacture qualified steam pressure transmitters for nuclear plant MS measurement. The under-the-bioshield temperature environment that these sensors can encounter requires a requalification of the conventional pressure transmitter. If the current conventional transmitter design does not support the qualification profile, then other options such as longer sensing lines to route the transmitter out from underneath the bioshield, special shielding, or installation of a pressure transducer with remote electronics will be considered.

5.5.3.1 Location

The location of the MS pressure transmitter sensing lines is on the DHRS tee piping, upstream of the MSIVs. The sensing lines are upstream of the MSIV to measure the pressure closest to the SG plenum as possible, but outside of containment and above the reactor pool water.

The pressure taps for the sensing lines are on the DHRS piping that splits off from the MS fitting. There are two pressure taps off of each DHRS pipe connecting to separate sensing lines. The sensing lines connect to transmitters that are located in an accessible position. There are eight transmitters total. There are four separation groups of transmitters for each MS pipe.

5.5.3.2 Installation

The installation of MS pressure transmitters is straightforward, as the piping that the sensing lines tap into is outside of containment and above the reactor pool water level. These sensing lines are designed in accordance with Reference 9.1.1.

5.5.3.3 Maintenance

Routine maintenance of the MS pressure transmitters consists of post cycle transmitter calibrations and visual inspections, so the transmitters must be accessible for this maintenance.

5.5.3.4 Qualification

Due to the potentially high temperature underneath the bioshield for DBE conditions, the currently available transmitters require requalification. If the current conventional transmitter design does not support the qualification profile, then other options such as longer sensing lines to route the transmitter out from underneath the bioshield, special shielding, or installation of a pressure transducer with remote electronics will be considered.

5.5.4 Future Work

1. {{

}}2(a),(b)

5.6 Feedwater Pressure and Decay Heat Removal System Outlet Pressure

5.6.1 Sensor Functions

There are no valves between the feedwater plenum of the SG and the DHR condenser in the area near the bottom of the DHRS condenser. Therefore, one pressure instrument is used to measure both functions. This instrument performs its feedwater pressure function when the DHRS valves (at the inlet to the DHRS heat exchanger) are closed, and performing its DHRS outlet pressure function when the DHRS valves are open (indicating the DHRS unit is active and MS and feedwater are isolated).

DHRS outlet pressure and feedwater pressure functions are listed in Table 5-1.

All of the functions apply to the one instrument for the purpose of designing and qualifying the sensor.

5.6.2 Sensor Requirements

Safety classification: B2

Seismic classification: Category I

Range: 0 to 1200 psia

Sensor accuracy: ±{{ }}2(a),(c) percent of calibrated span

Sensor response time: $\leq$ 0.5 seconds

Quantity: Six (three per DHRS condenser)

5.6.3 Sensor Description

The concept for the measurement of feedwater pressure and DHRS outlet pressure is a conventional pressure sensor. Because the location of the device is outside of containment, conventional means of pressure measurement is desired. The basic concept is to have three transmitters per DHRS condenser for a total of six separate pressure transmitters. These transmitters are waterproof for installation in the reactor pool on the DHRS condenser.

5.6.3.1 Location

The feedwater pressure and DHRS outlet pressure transmitters are located in the reactor pool at the bottom of the DHRS condenser.

5.6.3.2 Installation

The transmitters are located in the reactor pool and mounted to part of the DHRS condenser structure. This allows them to be in close proximity to their respective sensing lines. These sensing lines are designed in accordance with Reference 9.1.1. The signal cable is waterproof cable that routes the signal from the transmitter to the electrical panel near the platform above the vessel. From there the signal goes to the MPS cabinets.

5.6.3.3 Maintenance

The feedwater pressure and DHRS outlet pressure sensors are mounted and cables are routed such that maintenance can be performed while the instrument is in the refueling bay dry dock during refueling outages. As the instruments are on the outside of the containment vessel, they are accessible for maintenance calibrations, and replacements. Calibration of these transmitters is similar to conventional pressure transmitter calibrations.

5.6.3.4 Qualification

The DHRS pressure sensors perform a PAM Type D variable function. Sensors are specified to be conservatively qualified to operate in the reactor pool environment for any environment that requires DHRS actuation.

5.6.4 Future Work

1. {{

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

6.0 Reactor Coolant System Flow

In 2014, NuScale initiated a Phase I {{ }}2(a),(c),(d) for use in the NuScale design as an RCS flowmeter. The Phase 1 study had five objectives as follows:

- {{ }}2(a),(b)

Because the Phase 1 study yielded positive results, a Phase 2 project was initiated {{ }}2(a),(b) The objectives of the Phase 2 project were:

- {{ }}2(a),(b)

Table 6-1 RCS Flowmeter

Sensor	Range	Quantity	Function	Location	Safety and Risk Classification
Reactor coolant system flow	0 to 110%	4	RTS ESFAS F-1 interlock MCR indication Input to calorimetric calculations NSSS control Plant historian PAM Type D	In the lower section of containment below the steam generator section of the RPV	A1

6.1 Reactor Coolant System Flowmeter

6.1.1 Sensor Functions

The primary function of the reactor coolant flowmeter is to provide indication of RCS flow for MCR display and to provide reactor trip and ESFAS actions for low RCS flow conditions. Four channels of reactor coolant flow signals are required for the RTS and ESFAS functions. The flow signals are isolated and provided to the MCS for NSSS control functions, alarms, displays, and plant historian.

Safety-related functions are implemented by the MPS. Nonsafety-related functions are implemented in MCS using an isolated signal output from MPS rather than a direct connection to the sensors. RCS flow measurement functions are listed in Table 6-1.

6.1.2 Sensor Requirements

Safety classification: A1

Seismic classification: Category I

Range: 0 to 110 percent of full power flow

Sensor accuracy: {{

}}2(a),(c)

{{

}}2(a),(c)

Sensor response time: ≤ 1.0 second

Quantity: Four (one for each separation group)

6.1.3 Sensor Description

The preferred option for RCS flow measurement is the {{ }}2(a),(c),(d) with modification for the NuScale design. This device uses four pairs of ultrasonic transducers with each pair mounted on a nozzle. The four nozzles are mounted in four quadrants on the reactor vessel outer shell below the steam generators and {{

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

6.1.3.1 Location

The {{

}}2(a),(c),ECI They are in the proximity of the RCS cold temperature RTDs. This location was chosen to give a straight annulus for the reflection of the signal, and also to maximize the turbulent flow for a more homogenous flow profile.

6.1.3.2 Installation

The baseline reactor coolant flowmeter concept requires the mounting of {{

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

6.1.3.3 Maintenance

To ensure accessibility of the transducers for maintenance and replacement, the transducers are located in the lower downcomer region that is exposed when the upper reactor module is separated for refueling. The transducers can be removed and replaced, using access to the side of the vessel, should that be necessary.

Based on {{
}}2(a),(c),ECI routine maintenance of the transducer during or between cycles is not generally required. However, the electronics cabinet, which is located in a mild environment and readily accessible, may require periodic maintenance during refueling outages.

6.1.3.4 Qualification

Although the technology of this device is mature and currently commercially available for feedwater flow measurement applications, the harsh environment qualification of this device for the NuScale application is a new application of the existing product. The transducer itself will need to be qualified to CNV normal and DBE conditions. The possibility of submergence in an accident condition and during refueling requires the transducer to be water proof and submergible. This flowmeter is specified to meet the requirements of the applicable industry standards, both for the transducers and for the remote electronics processing units.

6.1.4 Future Work

1. {{

}}2(a),(b)

7.0 Level Measurement in the NPM

The initial approach for the RPV riser level measurement was to use a differential pressure transducer that required a reference leg located in containment. This approach had several engineering constraints, one of which was the need for a reference leg that would have to be separated during refueling operations. Other constraints that existed with the differential pressure method were reference leg temperature compensation, condensate pot cooling during a DBA environment, and the availability of a delta-pressure cell that could survive and operate in the containment environment. Radar technology was selected from the Phase 1 study as the best solution for level measurement for the NuScale design. Radar is currently used throughout the nuclear industry to measure spent fuel pool water level and has promising accuracy capability for the required level measurements within the NPM.

Radar is an approach to level measurement that uses a transceiver to transmit a radar signal through a guide tube or along a probe antenna. The time delay of the reflected wave establishes the distance from the radar antenna to the water and vapor interface. Through-air level units have been used in steam applications and offer a simple but efficient method of level measurement. Initial evaluation suggested the use of through-air radar in which a pulse, or series of pulses, is transmitted from a cone antenna through a guide tube or waveguide. Further investigation determined that through-air radar systems do not allow the use of remote electronics. However, several models of guided wave radar are available which allow the electronics packages to be located up to several hundred feet from the sensing probe.

Guided wave radar uses a solid metallic probe to conduct the electronic pulses rather than transmitted pulses through a waveguide.

There are three NPM related level measurements. The first two, pressurizer level and RPV riser level and containment water level, are baselined as radar technology sensors. The third measurement, DHRS level, is baselined as a level switch technology and is located on the DHRS piping.

Table 7-1 Pressurizer, RPV Riser, and Containment Water Level

Level Transmitters	Range	Quantity	Function	Location	Safety and Risk Classification
Pressurizer level and RPV riser level	0 to 100% (PZR level span is 130.1 inches) (RPV riser level span is estimated at 554.9 inches)	4	RTS ESFAS PAM Type B, C, and D variables L-2 interlock NSSS control MCR indication Plant historian	Top of RPV to upper core plate	A1
Containment water level	0 to 100% (containment level span is estimated at 683.5 inches)	4	ESFAS L-1 interlock PAM Type B, C, and D MCR indication NSSS control Plant historian	Top of containment to below the reactor recirculation valves	A1
DHRS level switch	N/A (discrete)	8	MCR indication Plant historian	On DHRS piping	B2

7.1 Pressurizer Level and Reactor Pressure Vessel Riser Level

7.1.1 Sensor Functions

The primary function of the pressurizer level and RPV riser level sensor is to provide inputs to the reactor trip and ESFAS actuations for safety system purposes. It is intended to indicate an increase or a decrease in RCS inventory, both of which have module protection implications. It also provides the necessary control room alarms and indications. For NSSS control, pressurizer level is maintained within an operating band by the CVCS makeup and the letdown functions.

Safety-related functions are implemented by the MPS. Nonsafety-related functions are implemented in MCS using an isolated signal output from MPS rather than a direct connection to the sensors. Pressurizer level measurement functions are listed in Table 7-1.

7.1.2 Sensor Requirements

Safety classification: A1

Seismic classification: Category I

Range: 0 percent to 100 percent calibrated span

(The span for the pressurizer level is 130.1 inches, and the span for the RPV riser level is estimated at 554.9 inches)

Sensor accuracy: ± {{ }}2(a),(c) percent of calibrated span

Sensor response time: ≤ 2 seconds

Quantity: Four (one for each separation group)

7.1.3 Sensor Description

The Phase 1 study on level documented the down-select process that selected radar level measurement sensor as the baseline approach to level measurement for pressurizer water level and RPV riser water level. One of the benefits of the radar approach to level measurement is the ability to measure RPV riser level and pressurizer level with the same instrument, hence the combined name of the measurement as “pressurizer level and RPV riser level.” However, further investigation indicated that through-air systems had drawbacks that made them unsuitable for use. As a result, the current design incorporates a guided wave radar method for measuring water level.

Radar is an approach to level measurement where the distance to the water surface is measured by short radar pulses propagated along a probe antenna. When the radar pulse reaches the water surface part of the radar signal is reflected back to the receiver. This level is determined based on the time difference of the sent and received pulses.

There are several manufacturers of radar level measurement devices. Phase 2 investigations have identified vendors with products that can be modified for use in the NPM.

7.1.3.1 Location

The pressurizer level and RPV riser level radar level sensor will be located inside the reactor vessel connected at an electrical penetration assembly. It incorporates a probe that runs the entire distance of the measurement. The pressurizer level and RPV riser level sensor spans the RPV head, through the pressurizer space, and down the hot leg riser to location near the upper core plate.

The electronics in several radar models have the ability to be located some distance from the probe head, which will allow mounting of the electronics in the MPS equipment rooms.

7.1.3.2 Installation

The radar level sensor consists of a radar probe antenna that is the wave guide for the transmitted signal. The probe will be attached near the top of the RPV and extend downward for the length of measurement. A pulsed signal is sent to the probe so that it propagates down the length of the probe and reflects off the vapor and liquid surface. The processing electronics are located some distance away from the probe. The details of the installation will be resolved after the Phase 2 study with the selection of manufacturers for this measurement.

7.1.3.3 Maintenance

Sensor calibration and maintenance are conducted at the processing electronics cabinet during a refueling outage. The sensor assembly should not need to be accessed for calibration activities.

7.1.3.4 Qualification

Qualification of several radar level sensing models have been performed for post-Fukushima spent fuel pool level sensing modifications. These qualifications have not included the pressures and temperatures found in the NuScale RPV and CNV environments. As part of the identified Future Work for this level sensing technology, proof-of-concept and pre-qualification testing will need to be conducted, so that confirmation of the capability of the sensor to survive and operate in the NuScale environment can be determined.

7.1.4 Future Work

1. {{

}}2(a),(b)

7.2 Containment Water Level

7.2.1 Sensor Functions

The primary function of the containment water level sensors is to provide a signal for ESFAS actuation for safety system purposes. It is intended to protect the core by activating the emergency core cooling system (ECCS) to allow recirculation of RCS water inventory in containment and into the RPV. It also provides the necessary control room alarms and indications and an isolated output is provided to the MCS for NSSS control functions.

Safety-related functions are implemented by the MPS. Nonsafety-related functions are implemented in MCS using an isolated signal output from MPS rather than a direct connection to the sensors. Containment water level measurement functions are listed in Table 7-1.

7.2.2 Sensor Requirements

Safety classification: A1

Seismic classification: Category I

Range: 0 to 100 percent calibrated span

The containment level span is estimated at 683.5 inches

Sensor accuracy: ± {{ }}$^{2(a),(c)}$ percent of calibrated span

Sensor response time: $\leq$ 2 seconds

Quantity: Four (one for each separation group)

7.2.3 Sensor Description

A radar assembly is mounted near the containment boundary interface to provide the radar emitting measurement instrument. The measured time span between the transmission and reflected signal return represents the water level in containment.

There are several manufacturers of radar level measurement devices. These vendors will be researched for a potential NuScale application.

7.2.3.1 Location

The radar instruments are located at the containment pressure boundary interface. The probe, acting as a wave guide, runs the entire distance of the measurement. For the containment water level sensor, this guide would run from the containment head to an elevation below its safety actuation point.

The electronics in several radar models have the ability to be located some distance from the probe head.

7.2.3.2 Installation

The radar level sensor consists of a radar probe antenna that is the wave guide for the transmitted signal. This probe is inserted in the top of the vessel such that its signal propagates down the distance to be measured and reflects off the vapor and liquid surface. The processing electronics are located some distance away from the probe. The details of the installation will be determined after the Phase 2 study and the selection of manufacturers for this measurement.

7.2.3.3 Maintenance

Sensor calibration is conducted at the processing electronics cabinet during a refueling outage. The sensor assembly should not need to be accessed for calibration activities.

7.2.3.4 Qualification

See Section 7.1.3.4 for information regarding the level sensor qualification.

7.2.4 Future Work

See Section 7.1.4 for Future Work items for this sensor function.

7.3 Decay Heat Removal System Level

7.3.1 Sensor Functions

The primary function of the DHRS heat exchanger level measurement is to provide binary (yes or no) indication of water level up to a certain height in the DHRS piping for control room indication. This liquid level acts as an indication of the operability of a train of DHRS with respect to determining a level of noncondensable gases.

DHRS level measurement functions are listed in Table 7-1.

7.3.2 Sensor Requirements

Safety classification: B2

Seismic classification: Category II

Range: N/A

Sensor accuracy: N/A

Sensor response time: N/A

Quantity: Eight, (four level switches per each DHRS unit)

7.3.3 Sensor Description

The concept for the DHRS level sensors is to use an industry standard level switch. The location of this sensor outside of containment allows access for maintenance or replacement. Several manufacturers offer level switches that would function adequately for this application.

7.3.3.1 Location

The DHRS level switches are located in the DHRS piping on the elbow immediately downstream of the DHRS actuation valves. Two level switches are located on each leg of piping.

7.3.3.2 Installation

The sensor taps are fitted into the DHRS steam piping. The switch inserts into the pipe taps and sends the signal electronically to the disconnect panel on MI cable or cable of similar nature that is waterproof. From the disconnect panel the signals are fed to the MCS for MCR indication.

7.3.3.3 Maintenance

The level switch is located so that it is accessible for maintenance and periodic calibration.

7.3.3.4 Qualification

This level switch will be designed to operate above the reactor pool and below the bioshield. Because there is no enclosure for the level switch, the switch will be tested for every condition associated with that area of the reactor pool, including potential submergence.

7.3.4 Future Work

1. {{

}}2(a),(b)

8.0 Summary and Conclusions

This report addresses the current state of the NuScale NSSS process sensors. It addresses the sensors, functions, sensor requirements, design concepts, sensor locations, installation details, maintenance approaches, and qualification methodology. The report also identifies the areas that need further investigation and study.

The normal and post-accident containment operating environments of the NPM are unique when compared to the containment of a conventional pressurized water reactor. The information presented in this report outlines the approach to monitoring the process variables and the future work and investigation that remains to be done.

The temperature measurements throughout the NPM utilize existing technology. The RTD was selected in all cases, excluding the ICI instruments, due to its nuclear experience, accuracy, and robust design.

The selection of pressure measurement devices had to consider the effects of radiation and temperature on electrical devices located in containment. In the conventional measurement approach the electronics are housed with the pressure sensor which would not survive in the containment environment. This report covers the selection of the containment pressure transducer with remote electronics as the solution for NPM pressure measurement. The advantage of this transducer configuration is that the electronics are not required to be in close proximity to the sensing element.

Measuring RCS flow in the RPV {{

}}2(c),(d),ECI

Level measurements in the containment and the RPV were initially going to be measured with a conventional differential pressure method using a condensing chamber and reference leg, but it was realized that the technique would not work in the NPM. Other solutions were investigated and it became apparent that the technology that showed the most promise was radar measurement technology. This technology is being investigated further.

All signals in containment are transmitted through radiation and temperature tolerant MI cable. {{

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

The future work items associated with each sensor function outline the remaining work to be done in that sensor area. As the sensor requirements and sensor design become more mature, the details of this sensor definition will be captured in the appropriate drawings and in the respective system design description documents.

In addition to providing information about the sensors for inclusion on their respective system design descriptions, this report also serves as the basis for future technical reports on advanced sensors.

9.0 References

9.1 Industry and Regulatory Standards

9.1.1 International Society of Automation, ISA–67.02.01–1999 “Nuclear Safety-Related Instrument Sensing Line Piping and Tubing Standards for Use in Nuclear Power Plants,” Research Triangle Park, N.C.

9.1.2 10 CFR 50.34(f), “Additional TMI-related requirements”

Enclosure 3:

Affidavit of Thomas A. Bergman, AF-0519-65562

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AFFIDAVIT of Thomas A. Bergman

I, Thomas A. Bergman, state as follows:

(1) I am the Vice President of Regulatory Affairs 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 report reveals distinguishing aspects about the process and method by which NuScale develops its nuclear steam supply advanced sensors.

NuScale has performed significant research and evaluation to develop a basis for this process and method 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 enclosed report entitled "Nuclear Steam Supply Advanced Sensors Technical Report," TR-0316-22048, Revision 2.The enclosure contains 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 May 17, 2019.

Thomas A. Bergman