Nuclear Steam Supply System Advanced Sensor Technical Report

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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, Nuclear Steam Supply System (NSSS) Advanced Sensor Technical Report, TR-0316-22048, Revision 0, 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 type 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, Nuclear Steam Supply System (NSSS) Advanced Sensor Technical Report, TR-0316-22048, Revision 0, 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 type 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 pool wall.

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, during normal operation, experiences a more severe temperature and radiation environment than the instrumentation in a conventional pressurized water reactor. Should the NPM experience a design-basis accident (DBA), the radiation, temperature and pressure levels in the CNV become significantly higher, creating 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 or run sense lines to conventional instruments that would be located inside a pressure boundary enclosure located outside containment.

In order 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 level, RPV riser level measurement, CNV water level measurement, and pressure measurement is {{ }}2(c) No Phase 2 for resistance temperature detectors (RTDs) is needed because RTDs are an existing nuclear qualified device, and are expected to meet the NuScale predicted environments with minimal modification. RTD development for NuScale goes directly to Phase 3.

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NuScale locates some of the NPM sensors adjacent to the RPV, most 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; describes the FOAK technologies as well as the conventional technologies to be utilized. This report describes the sensor technologies and their applications, 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 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(c) The Phase 1 report for temperature measurement recommended {{ }}2(c)

Pressure Measurement:

A non-conventional pressure measurement device was selected that provided an in-containment method of measuring pressure. This device uses an inside containment pressure transducer with remote processing electronics. {{ }}2(c) and environmental qualification.

Flow Measurement:

The {{ }}$^{2(c)}$ has been selected to measure RCS flow. The {{

}}$^{2(c)}$ was contracted to perform a Phase 1 preliminary evaluation of their {{ }}$^{2(c)}$ 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, which has started.

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

}}$^{2(c)}$

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 {{ }}$^{2(c)}$ device implemented in conjunction with a guide tube for containing the signal. The processing electronics for the radar unit is remote from the sensor cone assembly and located in a mild environment.

Summary:

Sensor development for the new non-conventional sensor functions is underway. Current NuScale contracts with companies such as {{ }}$^{2(c)}$ are pursuing this work. As the sensor requirements and concept design become more mature, the details of this sensor definition are captured in updated revisions of the NSSS sensor architecture report, the appropriate drawings and in the respective system design description documents.

1.0 Introduction

1.1 Purpose

The purpose of this NSSS Advanced Sensor Technical Report is to describe the 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 baseline approaches NuScale has taken to measure the NSSS process variables: flow, temperature, pressure, and level. This report addresses the work accomplished to-date, describe the FOAK technologies, and the conventional technologies to be utilized. This report describes sensor technology, its applications, maintenance, installation, and spares philosophy based on the NuScale environmental specification for containment, reactor pool, and bioshield environments.

The NSSS sensors are identified in the following sections. Functions associated with the NSSS sensors are included in this report. Those functions include PAM, RTS, ESFAS, low temperature overpressure protection (LTOP), core cooling indications, MCR indication, alarms, plant historian, and NSSS control.

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

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
- Baseline Concept
  - summary
  - 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
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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
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

Term	Definition
RTD	resistance temperature detector
RTS	reactor trip system
SG	steam generator
WR	wide range
ºF	degree Fahrenheit
%	percent

Table 1-2 Definitions

Term	Definition
NSSS controls	The NSSS control function 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/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 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 pool water level and underneath the bioshield.

2.0 Background

The NPM plant 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, and two steam generators integrated within the reactor pressure vessel and housed in a compact steel containment vessel. 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. The instrumentation, under normal conditions, experiences a more severe environment than the instrumentation in a conventional pressurized water reactor. Should the NPM experience a design-basis accident, the radiation levels in the CNV become significantly higher, creating 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, 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 pursued 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 {{

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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 NuScale reactor excluding qualification. Phase 2 developments for RCS flow measurement, pressurizer level, RPV riser level measurements, containment water level, and vessel-related pressure measurement are {{ }}2(c) Because nuclear qualified RTDs 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 NuScale module. A {{ }}2(c) Radiation aging, including design basis event dose, {{ }}2(c) NuScale has new qualification programs {{ }}2(c)

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 outside containment temperature and pressure sensors, but the other in-containment sensors solutions required new technology. 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.

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2.3 Maintenance Assumptions:

- All instruments are accessible, retrievable and replaceable while in the refueling bay dry dock.
- All in-vessel instruments shall be capable of calibration and capable of an in-situ function test upon vessel return to the operating bay.

2.4 Other Background, Design Guidance and Assumptions Items

- Taps or sensing lines through the containment vessel wall are not possible without moving the containment pressure boundary around them, or adding double isolation.
- {{ }}2(c)
- 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(c)
- Sensor accuracy does not include other channel uncertainties such as rack electronics uncertainties, process uncertainties, measurement and test equipment uncertainties, and/or harsh environment errors.
- Sensors located in the top of containment, or underneath the bioshield, are protected, shielded, or located away from the impact spray effects of high energy line break by pipe whip restraints, local shielding, or sensor location.
- The decay heat removal system (DHRS) unit is capable of supporting the mass of the submerged pressure, temperature, and level sensors.
- All sensor supporting structures planned for insertion in the RPV (as part of the RPV pressure boundary) are classified as Seismic Category 1. The seismic requirement classification in sections 4, 5, 6, and 7 of this report are for the sensor or sensing element only and does not apply to the sensor supporting structures.

2.5 Alternative Sensor Options

Through the process of investigation of suitable sensors for the NPM design, many technologies were investigated. A phase 1 contract with {{ }}2(c) 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 increased development risk. These technologies remain as back-up options for the NuScale design, in the event that a current baseline option becomes unsuitable.

2.6 Regulatory Acceptance Criteria and Guidance

2.6.1 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.

2.6.2 10 CFR 50, Appendix A, GDC 4, "Environmental and Dynamic Effects Design Bases" sets the requirements for systems, structures, and components important to safety are designed to accommodate the effects of environmental conditions associated with normal operations, maintenance, testing, and postulated accidents.

2.6.3 10 CFR 50.49, "Environmental Qualification of Electric Equipment Important to Safety for Nuclear Power Plants" (10 CFR 50.49).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 generally accepted methods 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.

2.6.4 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.

2.6.5 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 (e.g., concepts that may require tests and/or additional verification analyses for the first plant, the first three plants, and so forth).

2.6.6 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.

2.6.7 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.

2.6.8 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.

2.6.9 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.”

2.6.10 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.

2.6.11 10 CFR 50, Appendix A, GDC 13, “Instrumentation and Control,” requires there to be instrumentation to monitor variables over the anticipated ranges of normal operation, for anticipated operational occurrences, and for accident conditions.

3.0 Instrumentation Selection Process

3.1 Phase 1

In 2015, {{ }}2(c) 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. Studies were performed for NuScale on {{ }}2(c) The selected vendor 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(c) Based on the Phase 1 results, NuScale has proceeded with a phase 2 {{ }}2(c) The phase 2 proof-of-concept phase is currently underway.

In phase 1 {{ }}2(c)

3.2 Phase 2

The RCS flow instrumentation is actively undergoing Phase 2 development at this time. {{ }}2(c) The objective is to provide a {{ }}2(c) obtaining data over flow ranges corresponding to 0 percent to 110 percent of estimated full flow.

{{ }}2(c)

A contract has been issued for Phase 2 development of {{ }}2(c) The intent of this phase is to analyze and test various commercially available radar systems, with the objective of choosing the best product(s) for use in the NPM. {{ }}2(c) as the overseer of the test effort, is responsible for constructing test chambers and testing various {{ }}2(c) is also responsible for evaluating {{ }}2(c) An additional part of the Phase 2 effort is currently planned for {{ }}2(c) The intent is to validate performance of {{ }}2(c)

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

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

3.3 Phase 3 and Phase 4

There are {{ }}2(c)

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 NPM. The scope of the report was to develop approaches for measuring the following:

1. Narrow range RCS T_{hot} temperature
2. Wide range RCS T_{hot} temperature
3. Narrow range RCS T_{cold} temperature
4. Wide range RCS T_{cold} temperature
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

Note: The exact number of T_{hot} and T_{cold} RTDs in the RCS will be determined at later time after completion of CFD analysis and placement study.

Table 4-1 Temperature sensor list

Temperature Sensors	Range ºF	Quantity	Function	Location	Safety/Risk Classification
Narrow range RCS T_{hot} temperature	400ºF to 650ºF	12	RTS/ESFAS ESFAS T-4 interlock NSSS control Input to calorimetric calculation MCR indication Plant historian	Top of downcomer	A1

Temperature Sensors	Range ºF	Quantity	Function	Location	Safety/Risk Classification
Wide range RCS T_{hot} temperature	40ºF to 700ºF	4	PAM Type B ESFAS T-1 and T-2 interlocks Subcooling monitor Core cooling indication MCR indication Plant historian	Top of downcomer	A1
Narrow range RCS T_{cold} temperature	400ºF to 650ºF	8	NSSS control Input to calorimetric calculation MCR indication Plant historian	Downcomer below feedwater inlets	B2
Wide range RCS T_{cold} temperature	40ºF to 700ºF	4	LTOP LTOP T-1 enable Subcooling monitor Core cooling indication MCR indication Plant historian	Downcomer below feedwater inlets	A2
PZR liquid temperature	40ºF to 800ºF	2	NSSS control MCR indication Plant historian	Lower PZR	B2
PZR vapor temperature	40ºF to 800ºF	2	NSSS control MCR indication Plant historian	Upper PZR	B2
CNV air temperature	40ºF to 600ºF	2	NSSS control MCR indication Plant historian	Upper part of containment	B2

Temperature Sensors	Range ºF	Quantity	Function	Location	Safety/Risk Classification
MS temperature	100ºF to 700ºF	8	RTS/ESFAS PAM Type D NSSS control Input to calorimetric calculation MCR indication Plant historian	Upper part of main steam isolation valve (MSIV) on MS pipe	A1
Feedwater temperature	40ºF to 440ºF	6	NSSS control Input to calorimetric calculation MCR indication Plant historian	Downstream of feedwater isolation valve (FWIV) on feedwater (FW) pipe	B2
DHRS outlet temperature	40ºF to 440ºF	4	PAM Type D MCR indication Plant historian	Bottom of DHRS unit	B2
Under-the-bioshield temperature	40ºF to 700ºF	4	RTS/ESFAS PAM Type D MCR indication Plant historian	Under the bioshield	A1

4.1 Narrow Range Reactor Coolant System T_{hot} Temperature

4.1.1 Sensor Functions

The primary function of the narrow range RCS T_{hot} temperature sensors is to provide temperature measurements for the T_{hot} reactor trip, DHRS actuation, and NSSS control functions. To attain an accurate narrow range T_{hot} indication, multiple sensors are required. By taking multiple narrow range T_{hot} measurements at several locations in the quadrant and averaging them, an accurate T_{hot} measurement is achievable. The averaging process is expected to compensate for any streaming effects that may be present at the top of the hot leg riser.

Narrow range RCS T_{hot} temperature functions:

- reactor trip – RCS T_{hot} high
- ESFAS – DHRS actuation – RCS T_{hot} high
- ESFAS – T-4 interlock
- NSSS control
- input to primary side calorimetric calculation
- MCR indication
- plant historian

4.1.2 Sensor Requirements

Safety classification: A1

Seismic classification: Category I

Range: 400 to 650 degree Fahrenheit

Sensor accuracy: ± {{ }}$^{2(c)}$ degree Fahrenheit

Sensor response time: $\leq$ 6 seconds

Quantity: twelve; four separation groups of three sensors each.

4.1.3 Baseline Concept

4.1.3.1 Summary

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

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4.1.3.2 Location

The T_{hot} 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, forming separation groups, around the pressure vessel directly below the pressurizer baffle plate location. The RTDs are not directly exposed to the RPV environment as they are mounted in thermowells. As such, they will need to be qualified for the containment environment.

4.1.3.3 Installation

The sensors are installed in thermowells on the RPV vessel and inside containment. They will be qualified to operate in the containment environment but they 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 design basis event (DBE) environments.

Twelve sensing elements, three per separation group (A, B, C, and D) are planned. They are mounted below the pressurizer baffle plate section to obtain safety-related T_{hot} narrow range temperature measurement. For this baseline configuration one of the three narrow range T_{hot} RTDs share a thermowell with the wide range T_{hot} RTD (as a dual element wide range (WR)/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.

4.1.3.4 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 and/or after the refueling outage, requiring 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.

4.1.3.5 Qualification

The NR T_{hot} RTDs and respective cables will be qualified to operate in the containment normal conditions and DBE conditions in accordance with industry standards.

4.1.4 Future Work

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4.2 Wide Range Reactor Coolant System T_{hot} Temperature

4.2.1 Sensor Functions

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

RCS T_{hot} temperature wide range functions:

- PAM Type B variable
- ESFAS – T-2 and T-3 interlocks
- core cooling indication
- MCR indication
- plant historian

4.2.2 Sensor Requirements

Safety classification: A1

Seismic classification: Category I

Range: 40 to 700 degree Fahrenheit

Sensor accuracy: ± {{ }}$^{2(c)}$ degree Fahrenheit

Sensor response time: ≤ 6 seconds

Quantity: Four RTDs, one per quadrant

4.2.3 Baseline Concept

4.2.3.1 Summary

The wide range T_{hot} RTDs have a wide range of measurement (40 degree Fahrenheit to 700 degree Fahrenheit) and are installed in thermowells in the same vicinity as the narrow range T_{hot} RTDs. The RTD leads are routed from the sensor up to the containment head, through the electrical penetration assemblies (EPAs) on the CNV head, to the MPS electronics cabinets.

4.2.3.2 Location

The wide range T_{hot} 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, forming separation groups, around the pressure vessel directly below the pressurizer baffle plate location. The RTDs themselves are not be exposed to the RPV environment, but will be qualified for the containment environment.

4.2.3.3 Installation

Four RTDs total, with one per separation group (A, B, C, and D), are installed in thermowells below the pressurizer baffle plate section to obtain the wide range T_{hot} temperature measurement. These RTDs are installed in thermowells on the containment side of the RPV vessel and will be qualified to operate in the containment normal and DBE environments. For this baseline configuration the wide range T_{hot} RTD shares a thermowell with one of the narrow range T_{hot} 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.

4.2.3.4 Maintenance

The temperature elements are routed and mounted 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 and/or after the refueling outage, requiring 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.

4.2.3.5 Qualification

The wide range T_{hot} RTDs and respective cables will be qualified to operate in the containment normal conditions and DBE conditions in accordance with industry standards.

These RTDs are designed to operate in normal containment conditions, containment DBE pressure, temperature, radiation conditions, and conditions associated with the post-accident duration requirements. The associated cabling and connectors are designed and tested for the same normal and DBE conditions.

4.2.4 Future Work

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4.3 Narrow Range Reactor Coolant System T_{cold} Temperature

4.3.1 Sensor Functions

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

RCS narrow range T_{cold} temperature functions:

- NSSS control - computation of average temperature for control functions
- input to primary side calorimetric calculation
- MCR indication
- plant historian

4.3.2 Sensor Requirements

Safety classification: B2

Seismic classification: Category II

Range: 400 to 650 degree Fahrenheit

Sensor accuracy: ± {{ }}$^{2(c)}$ degree Fahrenheit

Sensor response time: $\leq$ 6 seconds

Quantity: Eight; four separation groups of two sensors each

4.3.3 Baseline Concept

4.3.3.1 Summary

Two T_{cold} narrow range RTD signals per RPV quadrant are sent to the MPS that implement signal conditioning algorithms to determine an average reactor coolant system narrow range T_{cold} value for each quadrant (separation group). An average T_{cold} signal is preferable to a single T_{cold} signal in order to compensate for temperature streaming effects in the RCS.

4.3.3.2 Location

The narrow range T_{cold} RTDs are located in thermowells on the side of the RPV in the lower downcomer region, near the {{ }}$^{2(c)}$. These thermowell inserts are located in quadrants, forming separation groups, 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 qualified for the containment environment. The RTD leads are routed up to the containment head via MI cable, through the EPAs on the CNV head, to the MCS electronics cabinets.

4.3.3.3 Installation

Eight RTDs, two per channel (A, B, C, and D), 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 baseline configuration one of the two narrow range T_{cold} RTDs share a thermowell with the WR T_{cold} RTD (dual element WR and NR RTD) in each quadrant, to minimize the number of thermowell installations in the vessel.

4.3.3.4 Maintenance

The temperature elements are routed and mounted 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 allow for RTD removal or replacement, while in the refueling bay dry dock.

An RTD cross calibration is required before and/or after the refueling outage, requiring 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.

4.3.3.5 Qualification

The narrow range T_{cold} RTDs and respective cables are tested for operability in the containment pressure vessel normal environment.

4.3.4 Future Work

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4.4 Reactor Coolant System Wide Range T_{cold} Temperature

4.4.1 Sensor Functions

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

RCS T_{cold} temperature wide range functions:

- LTOP (with wide-range RCS pressure)
- ESFAS T-1 interlock
- core cooling indication
- MCR indication
- plant historian

4.4.2 Sensor Requirements

Safety classification: A2

Seismic classification: Category I

Range: 40 to 700 degree Fahrenheit

Sensor accuracy: ± {{ }}$^{2(c)}$ degree Fahrenheit

Sensor response time: $\leq$ 6 seconds

Quantity: Four temperature sensors. No installed spares are planned for the wide range T_{cold} sensor function, in order to minimize thermowells and conductors passing through the penetration.

4.4.3 Baseline Concept

4.4.3.1 Summary

The wide-range T_{cold} RTDs are inserted in thermowells located in the lower downcomer near the narrow range T_{cold} RTDs. The wide range RTDs are exposed to the containment environment as the thermowell act as the pressure boundary between the RPV and CNV environments.

4.4.3.2 Location

The wide-range T_{cold} RTDs are located in thermowells located in the lower downcomer of the RPV, downstream of the steam generators, at the same elevation as the narrow range T_{cold} RTDs.

4.4.3.3 Installation

The wide-range T_{cold} RTDs are inserted in thermowells located in the lower downcomer section of the RPV. For this baseline configuration the wide range T_{cold} RTD share a thermowell with one of the narrow range T_{cold} RTDs (as a dual element WR/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.

4.4.3.4 Maintenance

The RTDs are routed and mounted 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 and/or after the refueling outage, requiring 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.

4.4.3.5 Qualification

The LTOP function of these RTDs requires the RTDs to meet the harsh environment qualification requirements of industry standards.

4.4.4 Future Work

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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/shutdown) control.

Pressurizer liquid temperature measurement functions:

- NSSS controls (startup/shutdown)
- MCR indication
- plant historian

4.5.2 Sensor Requirements

Safety classification: B2

Seismic classification: Category II

Range: 40 to 800 degree Fahrenheit

Sensor accuracy: ± {{ }}$^{2(c)}$ degree Fahrenheit

Sensor response time: $\leq$ 6 seconds

Quantity: Two temperature sensors

4.5.3 Baseline Concept

4.5.3.1 Summary

The pressurizer liquid temperature measurement provides pressurizer liquid temperature indication to the MCR and plant historian for operational actions during start-up and shutdown. Although thermocouples could easily be chosen for this temperature measurement as the accuracy does not need to be as great as other RPV temperature measurements, RTDs are preferred in order to take advantage of the qualification testing program expected of some of the other RPV related RTDs, for the containment environment requirements. These RTDs are inserted into thermowells to insure RPV pressure boundary conditions are met.

4.5.3.2 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. The

RTDs sense the pressurizer temperature through thermowells and are tested for operability in the containment environment.

4.5.3.3 Installation

The RTDs are mounted in thermowells in the lower section of the pressurizer and will be tested to operate in the normal containment environment. The RTD cabling is MI cables, to protect the electronic signal from the containment environment conditions. The RTD 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.

4.5.3.4 Maintenance

The temperature elements are mounted and 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. The calibration methodology for these sensors is an item for the Future Work section below.

4.5.3.5 Qualification

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

4.5.4 Future Work

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4.6 Pressurizer Vapor Temperature

4.6.1 Sensor Functions

The primary function of the pressurizer vapor temperature measurement is to provide pressurizer vapor temperature 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:

- NSSS controls
- MCR indication
- plant historian

4.6.2 Sensor Requirements

Safety classification: B2

Seismic classification: Category II

Range: 40 to 800 degree Fahrenheit

Sensor accuracy: ± {{ }}2(c) degree Fahrenheit

Sensor response time: ≤ 6 seconds

Quantity: Two temperature sensors.

4.6.3 Baseline Concept

4.6.3.1 Summary

The pressurizer vapor temperature measurement provides pressurizer vapor temperature indication to the MCR and plant historian for operational actions during start up and shutdown. Although thermocouples could easily be chosen for this temperature measurement as the accuracy does not need to be as great as other RPV temperature measurements, RTDs are preferred in order to take advantage of the qualification testing program expected of some of the other RPV related RTDs, for the containment environment. These RTDs are inserted into thermowells to insure RPV pressure boundary conditions are met.

4.6.3.2 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. The RTDs sense the RCS temperature through thermowells and are tested for operability in the containment environment.

4.6.3.3 Installation

The two RTDs are installed in thermowells in the vapor section of the pressurizer and will be tested to operate in the normal operating containment environment. The RTD cabling is protected from the containment environment by MI cables. The RTD 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.

4.6.3.4 Maintenance

The temperature elements are routed and mounted such that maintenance can be performed. The RTDs are accessible, and retrievable for necessary maintenance and/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.

4.6.3.5 Qualification

The pressurizer vapor temperature RTDs and respective cables will be tested 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 measurement is to provide general containment atmospheric temperature for operator display. It also provides indication to the plant historian and be available for NSSS control functions.

Containment air temperature measurement functions:

- NSSS controls
- MCR indication
- plant historian

4.7.2 Sensor Requirements

Safety classification: B2

Seismic classification: Category II

Range: 40 to 600 degree Fahrenheit

Sensor accuracy: ± {{   }}$^{2(c)}$ degree Fahrenheit

Sensor response time: $\leq$ 6 seconds

Quantity: Two temperature sensors

4.7.3 Baseline Concept

4.7.3.1 Summary

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 tested and proven to operate in the normal containment environment.

4.7.3.2 Location

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

4.7.3.3 Installation

The two RTDs are installed on mountings near the top inside of containment. They are not housed in a thermowell, but mounted such that the temperature sensing can occur in the environment 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.

4.7.3.4 Maintenance

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

The calibration method for these RTDs has not yet been developed, and is added to the Future Work section below.

4.7.3.5 Qualification

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

4.7.4 Future Work

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4.8 Main Steam Temperature

4.8.1 Sensor Functions

The primary purpose of the MS temperature is to determine MS superheat for RTS/ESFAS actuations. This sensor is also required for MCR indication, calculations of the calorimetric, and NSSS Control. The MS temperature measurement also serves as the DHRS inlet temperature measurement.

MS temperature measurement functions:

- reactor trip – high steam superheat (with MS pressure)
- reactor trip – low steam superheat (with MS pressure)
- ESFAS – DHRS actuation - high steam superheat (with MS pressure)
- ESFAS – DHRS actuation - low steam superheat (with MS pressure)
- NSSS control (MCS and PCS)
- PAM Type D variable (DHRS inlet temperature)
- input to secondary side calorimetric calculation
- MCR indication
- plant historian

4.8.2 Sensor Requirements

Safety classification: A1

Seismic classification: Category I

Range: 100 to 700 degree Fahrenheit

Sensor accuracy: ± {{ }}2(c) degree Fahrenheit

Sensor response time: $\leq$ 6 seconds

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

4.8.3 Baseline Concept

4.8.3.1 Summary

The baseline concept for the MS temperature measurement is to use RTDs inserted in thermowells in the outside containment MS pipe sections on the upstream side of the MSIVs. Because the application is a pipe structure, conventional technology can be implemented. There are two MS pipes exiting containment, requiring four thermowells per pipe. The eight sensing elements (four per pipe) are routed to separation groups A, B, C, and D, in the MPS for calculation of steam superheat, and through isolators for other functions. The RTDs are custom made to fit in the thermowells, but otherwise, the device is commercially available.

4.8.3.2 Location

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

4.8.3.3 Installation

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

4.8.3.4 Maintenance

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

The calibration methodology for these RTDs {{ }}$^{2(c)}$

4.8.3.5 Qualification

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

4.8.4 Future Work

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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:

- NSSS control
- input to secondary side calorimetric calculation
- MCR indication
- plant historian

4.9.2 Sensor Requirements

Safety classification: B2

Seismic classification: Category II

Range: 40 to 440 degree Fahrenheit

Sensor accuracy: ± {{ }}2(c) degree Fahrenheit

Sensor response time: $\leq$ 6 seconds

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

4.9.3 Baseline Concept

4.9.3.1 Summary

The baseline 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, there are 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 custom made to fit in the thermowells, but otherwise, the device is commercially available.

4.9.3.2 Location

The basic concept is to have three thermowells per feedwater inlet pipe for three separate RTDs. The location of these RTDs is underneath the bioshield, on the upstream side of the FWIVs, but downstream of the feedwater separation flange. {{

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4.9.3.3 Installation

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

4.9.3.4 Maintenance

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

The calibration methodology for these RTDs {{

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4.9.3.5 Qualification

The feedwater temperature RTDs, although not safety-related, will be tested 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, although some tailoring for fit is anticipated.

4.9.4 Future Work

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4.10 Decay Heat Removal System Outlet Temperature

4.10.1 Sensor Functions

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

DHRS temperature measurement functions:

- PAM Type D variable
- MCR indication
- plant historian

4.10.2 Sensor Requirements

Safety classification: B2

Seismic classification: Category I

Range: 40 to 440 degree Fahrenheit

Sensor accuracy: ± {{ }}2(c) degree Fahrenheit

Sensor response time: $\leq$ 6 seconds

Quantity: Four (two RTDs per DHRS unit, two DHRS units)

4.10.3 Baseline Concept

4.10.3.1 Summary

The baseline 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 means of temperature measurement is desired. The DHRS condenser will have thermowells to accommodate the RTD/thermowell approach to measurement. The RTDs must be waterproof and submergible in order to work in the submerged DHRS condenser.

The RTDs can be custom made to fit in the thermowells, and, 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 the best indication of steam generator inlet temperature.

4.10.3.2 Location

The basic concept is to have 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. This location is also reflected in the DHRS piping and instrumentation diagrams.

4.10.3.3 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.

4.10.3.4 Maintenance

The temperature elements are mounted and routed such that maintenance can be performed. The RTDs must be accessible and retrievable for necessary maintenance and/or replacement during a refueling outage. 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.

The calibration methodology for these RTDs {{

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4.10.3.5 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 {{

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4.10.4 Future Work

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4.11 Under-the-Bioshield Temperature

4.11.1 Sensor Functions

The primary function of the under-the-bioshield temperature sensors is to acquire temperature measurements for the associated reactor trip, containment isolation, and DHRS actuation. These sensors also provide under-the-bioshield temperature indication as a PAM Type D variable and provide indication to the MCR.

Under-the-bioshield temperature functions:

- reactor trip – high under-the-bioshield temperature
- ESFAS – containment isolation - high under-the-bioshield temperature
- ESFAS – decay heat removal actuation - high under-the-bioshield temperature
- PAM Type D variable
- MCR indication
- plant historian

4.11.2 Sensor Requirements

Safety classification: A1

Seismic classification: Category I

Range: 40 to 700 degree Fahrenheit

Sensor accuracy: ± {{ }}2(c) degree Fahrenheit

Sensor response time: ≤ 6 seconds

Quantity: Four, one for each separation group

4.11.3 Baseline Concept

4.11.3.1 Summary

The baseline 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 separation groups A, B, C, and D, in the MPS for under-the-bioshield environment based actuation.

4.11.3.2 Location

The location of the RTDs are outside of containment, underneath the bioshield, on the pool wall near the disconnect panel.

4.11.3.3 Installation

The RTDs are mounted on the 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.

4.11.3.4 Maintenance

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

The calibration methodology for these RTDs {{

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4.11.3.5 Qualification

The under-the-bioshield RTDs and respective cables will be qualified to operate in the under-the-bioshield environment. The RTDs will have a qualification that envelopes the under-the-bioshield normal and DBE environment. The qualification envelope for these RTDs may encompass the containment environment as well as the bioshield environment so that the same RTD can be used in both locations.

4.11.4 Future Work

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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 NPM. The scope of the study was to investigate and develop approaches for measuring the following:

1. Pressurizer pressure
2. RCS pressure - wide range
3. Containment pressure - narrow range
4. Containment pressure - wide range
5. MS pressure
6. Feedwater/DHRS outlet pressure

Background:

A Phase I contract was issued to {{ }}2(c) for pressure measurement that meet the requirements of the NPM. The researched pressure-sensing instrumentation was required to measure pressure over various ranges as 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, {{

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Outside Containment Pressure Sensors:

The outside containment pressure sensors, 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 2.5, 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/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/D Core cooling indication NSSS control MCR indication Plant historian	Near top of PZR in CNV	A2
Narrow range containment pressure	0 to 20	4	RTS/ESFAS NSSS control RCS leak detect MCR indication Plant historian	Upper part of CNV	A1
Wide range containment pressure	0 to 1200	2	PAM Type B/C/D Core cooling indication MCR indication Plant historian	Upper part of CNV	B2

Pressure Sensors	Range (psia)	Quantity	Function	Location	Safety/Risk Classification
MS pressure	0 to 1200	8	RTS/ESFAS PAM Type D Steam superheat NSSS control Input to calorimetric calculation MCR indication Plant historian	Upstream of MSIVs on DHRS tee	A1
Feedwater pressure/DHRS outlet pressure	0 to 1200	6	PAM Type D NSSS control Input to calorimetric calculation MCR indication Plant historian	Bottom of DHRS unit	B2

5.1 Pressurizer Pressure

5.1.1 Sensor Functions

The primary function of the pressurizer pressure measurement is to protect the reactor coolant system from overpressure and low pressure which could lead to overheating in the reactor core. 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 for non-safety pressurizer pressure control functions.

Pressurizer pressure functions:

- reactor trip - pressurizer pressure high
- reactor trip - pressurizer pressure low
- reactor trip - pressurizer pressure low low
- ESFAS – DHRS actuation – pressurizer pressure high
- ESFAS – DHRS – pressurizer pressure low
- ESFAS – DHRS – pressurizer pressure low low
- ESFAS – chemical and volume control system (CVCS) isolation – pressurizer pressure low
- ESFAS – chemical and volume control system (CVCS) isolation – pressurizer pressure low low

- NSSS control
- MCR indication
- plant historian

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(c) percent of calibrated span

Sensor Response time: ≤ 0.4 seconds

Quantity: Four, one for each separation group

5.1.3 Baseline Concept

5.1.3.1 Summary

The pressure transducer with remote electronics, described in section 5.0, was selected for the baseline pressurizer pressure sensor. The primary reason for this choice was its increased temperature survivability, radiation survivability and operability, compared to conventional pressure transmitters. (Due to the high normal and DBE temperature and radiation conditions in containment, a conventional nuclear pressure transmitter is not able to survive and operate in the containment environment.) This sensor concept has the radiation and temperature tolerant transducer in containment with the conditioning/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.

5.1.3.2 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.

5.1.3.3 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. It is valved into sensing lines. These sensing lines are designed in accordance with Reference 9.1.1. The transduced signal is routed out of containment via MI cable and through the containment penetrations. From there, the signal goes to the processing electronics cabinets located in a mild environment.

5.1.3.4 Maintenance

During refueling outages, the transducer and the associated electronics can be accessed for calibration, and possible replacement. The sensing lines have a valve manifold configuration allowing for isolation and calibration of the transducer. The power supplies are housed in the processing cabinets in a mild environment, and some routine power supply maintenance is expected.

5.1.3.5 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

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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 wide-range pressure indication for PAM and LTOP. Isolated output signals are also provided for NSSS control purposes.

RCS pressure wide-range functions:

- PAM Type B, C, and D variables

- degrees of subcooling calculation (PAM Type B variable)
- LTOP (with wide-range RCS T_{HOT} temperature)
- core cooling Indication
- NSSS controls
- MCR indication
- plant historian

5.2.2 Sensor Requirements

Safety classification: A2

Seismic classification: Category I

Range: 0 to 2500 psia

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

Sensor response time: $\leq$ 0.4 seconds

Quantity: Four, one for each separation group

5.2.3 Baseline Concept

5.2.3.1 Summary

The pressure transducer with remote electronics, described in section 5.0, was selected for the baseline wide range RCS pressure sensor. The primary reason for this choice was its increased temperature survivability, radiation survivability, and operability, compared to conventional pressure transmitters. (Due to the high normal and DBE temperature and radiation conditions in containment, a conventional nuclear pressure transmitter is not able to survive and operate in the containment environment.) This sensor concept has the radiation and temperature tolerant transducer in containment with the conditioning/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 and other downstream equipment.

5.2.3.2 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.

5.2.3.3 Installation

The pressure transducer is installed on a mounting in containment. It is valved into sensing lines. These sensing lines are designed in accordance with Reference 9.1.1. The transduced signal is routed via MI cable through the containment penetrations, out of containment to the conditioning/processing electronics.

5.2.3.4 Maintenance

During refueling outages, the transducer and the associated electronics can be accessed for calibration, and possible replacement. The sensing lines have a valve manifold configuration allowing for isolation and calibration of the transducer. The power supplies are housed in the processing cabinets in a mild environment, and some routine power supply maintenance is expected.

5.2.3.5 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.

5.2.4 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 measurement is to provide an accurate measurement of containment pressure to supply the high containment pressure reactor trip and the ESFAS actuation for containment isolation and DHRS activation. An isolated output of the narrow range containment pressure signal also supply the NSSS control systems. 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 control room alarms, control room displays, and plant historian.

Containment pressure narrow-range functions:

- reactor trip - high containment pressure
- ESFAS – containment isolation - high containment pressure
- ESFAS – DHRS activation - high containment pressure
- ESFAS – CVCS isolation - high containment pressure
- MCR indication

- NSSS control
- plant historian

5.3.2 Sensor Requirements

Safety classification: A1

Seismic classification: Category I

Range: 0 to 20 psia

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

Sensor response time: $\leq$ 0.4 seconds

Quantity: Four, one for each separation group.

5.3.3 Baseline Concept

5.3.3.1 Summary

The pressure transducer with remote electronics, described in section 5.0, was selected for the baseline narrow range containment pressure sensor. The primary reason for this choice was its increased temperature survivability, radiation survivability, and operability, compared to conventional pressure transmitters. (Due to the high normal and DBE temperature and radiation conditions in containment, a conventional nuclear pressure transmitter is not able to survive and operate in the containment environment.) This sensor concept has the radiation and temperature tolerant transducer in containment with the conditioning/processing electronics located in a milder environment outside containment.

Four pressure transducers are located in containment and senses the pressure in the environment in which they are located. This sensing concept calls for a transducer that is located inside containment, near the top of containment (no sensing lines required because the transducer is in the environment in which it is sensing). 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 analog electronics outside containment and provide a signal to the MPS or other downstream equipment.

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.

5.3.3.2 Location

The narrow range 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 remote processing electronics are located in a mild environment outside containment.

5.3.3.3 Installation

Four narrow range pressure transducers, one for each separation group, are installed in containment in four different locations, supplying four different separation groups (A, B, C, and D). Each pressure transducer senses the pressure environment in which it is located. The transducers are located in a place that allows them to maintained and replaced during refueling outages. The pressure signal is routed on MI cables, through the containment penetration and to the analog sensor processing electronics, and then to the MPS system. The signal goes through an isolator for MCS processing, MCR indication and plant historian functions.

5.3.3.4 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, in which some routine power supply maintenance is expected.

5.3.3.5 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

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}}2(c)

5.4 Wide Range Containment Pressure

5.4.1 Sensor Functions

The primary function of the wide range containment pressure measurement is to provide pressure measurement for post-accident monitoring. It is a PAM Type B, C, and D variable. Wide range containment pressure is also used to supply control room alarms, control room displays, and plant historian.

Wide range containment pressure functions:

- PAM Type B, C, and D variables
- core cooling indication
- MCR indication
- plant historian

5.4.2 Sensor Requirements

Safety classification: B2

Seismic classification: Category I

Range: 0 to 1200 psia

Sensor accuracy: ± {{ }}2(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 Baseline Concept

5.4.3.1 Summary

The pressure transducer with remote electronics, described in section 5.0, was selected for the baseline wide range containment pressure sensor. The primary reason for this choice was its increased temperature survivability, radiation survivability, and operability, compared to conventional pressure transmitters. (Due to the high normal and DBE temperature and radiation conditions in containment, a conventional nuclear pressure transmitter is not able to survive and operate in the containment environment.) This sensor concept has the radiation and temperature tolerant transducer in containment with the conditioning/processing electronics located in a milder environment outside containment.

This sensing concept calls for two transducers located inside containment, near the top of containment (no sensing lines required because the transducer is in the environment in which it is sensing). 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 and provide a 4 to 20 mA signal to the MPS or other downstream equipment.

5.4.3.2 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.

5.4.3.3 Installation

Two wide range pressure transducers are installed in containment in two locations and 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. The signal goes through an isolator for MCS processing, MCR indication and plant historian functions.

5.4.3.4 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, in which some routine power supply maintenance is expected.

5.4.3.5 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 MS pressure measurement 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/ESFAS actuations, PAM Type D variable function, as well as the superheat calculation, NSSS controls, and MCR indication.

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

MS pressure functions:

- reactor trip – high steam superheat (with MS temperature)
- reactor trip – low steam superheat (with MS temperature)
- reactor trip – low MS pressure
- reactor trip - low-low MS pressure
- reactor trip – high MS pressure
- ESFAS – DHRS actuation - high steam superheat (with MS temperature)
- ESFAS – DHRS actuation - low steam superheat (with MS temperature)
- ESFAS – DHRS actuation - high MS pressure
- ESFAS – DHRS actuation - low MS pressure
- ESFAS – DHRS actuation - low-low MS pressure
- NSSS control
- steam superheat calculation
- input to secondary side calorimetric calculation
- PAM Type D variable (as DHRS inlet pressure)
- MCR indication
- plant historian

5.5.2 Sensor Requirements

Safety classification: A1

Seismic classification: Category I

Range: 0 to 1200 psia

Sensor accuracy: ± {{ }}[2(c)] percent of calibrated span

Sensor response time: ≤ 0.5 seconds

Quantity: Eight, four for each MS pipe, two MS pipes.

5.5.3 Baseline Concept

5.5.3.1 Summary

The baseline concept for the MS pressure sensors is to 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 (as described in sections 5.1 through 5.4) will be considered.

5.5.3.2 Location

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

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

5.5.3.3 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 pool water level. These sensing lines are designed in accordance with Reference 9.1.1. The sensing line taps are on the DHRS piping; the transmitters are located nearby, and accessible for cyclic maintenance.

5.5.3.4 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. The sensing lines are valved into the transmitters so the valves are accessible.

5.5.3.5 Qualification

The baseline concept is to install conventional pressure transmitters for this application. {{

}}2(c), ECI

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}}2(c)

5.5.4 Future Work

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}}2(c)

5.6 Feedwater Pressure/Decay Heat Removal System Outlet Pressure

5.6.1 Sensor Functions

Because 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, one pressure instrument is used to measure both functions. As such, the feedwater pressure sensor and the DHRS outlet pressure sensor are the same instrument. This instrument performs its feedwater pressure function when the DHRS valves (at the inlet to the DHRS) 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 functions:

- input to secondary side calorimetric calculation
- PAM Type D variable
- MCR indication
- plant historian

Feedwater pressure functions:

- NSSS control
- input to secondary side calorimetric calculation
- MCR indication
- plant historian

All of the above functions apply to the one instrument, no matter what function it is supplying, 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(c) percent of calibrated span

Sensor response time: ≤ 0.5 seconds

Quantity: Six, three per DHRS unit, two DHRS units

5.6.3 Baseline Concept

5.6.3.1 Summary

The basic concept for the measurement of feedwater pressure/DHRS outlet pressure is with a conventional pressure measurement device. 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 pool on the DHRS condenser, and are used for both feedwater pressure and DHRS outlet pressure functions.

5.6.3.2 Location

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

5.6.3.3 Installation

The transmitters are located in the pool, and mounted to part of the DHRS condenser structure, that 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.

5.6.3.4 Maintenance

The feedwater pressure /DHRS outlet pressure sensors are mounted and 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.

5.6.3.5 Qualification

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

5.6.4 Future Work

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}}2(c)

6.0 Reactor Coolant System Flow

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

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}}2(c)

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

- {{

}}2(c) and therefore chosen as the baseline measurement approach.

Table 6-1 RCS flowmeter

Sensor	Range (%)	Quantity	Function	Location	Safety/Risk Classification
Reactor cooling system flow	0 to 110 %	4	RTS Trip/ CVCS isolation – low-low flow ESFAS-demineralized water system isolation – Low flow NSSS control Input to calorimetric calculations PAM Type D MCR indication Plant historian	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 on low flow and low-low flow. Four channels of reactor coolant flow signals are required for the RTS and ESFAS functions, and these flow signals are passed to MCS for control functions, alarms, displays, and plant historian.

RCS flow measurement functions:

- reactor trip – RCS low-low flow
- ESFAS – CVCS dilution isolation – RCS low flow
- ESFAS – demineralized water system isolation – RCS low flow
- NSSS Control
- PAM Type D variable
- input to primary side calorimetric calculation
- MCR indication
- plant historian

6.1.2 Sensor Requirements

Safety classification: A1

Seismic classification: Category I

Range: 0 to 110 percent of full power flow

Sensor accuracy: {{

}}2(c)

Sensor response time: ≤ 1.0 second

Quantity: Four, one for each separation group

6.1.3 Baseline Concept

6.1.3.1 Summary

As discussed in section 6.0 above, the best option for RCS flow measurement is the {{ }}2(c) 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 vessel quadrants on the reactor vessel outer shell below the steam generators and {{

}}2(c), ECI

6.1.3.2 Location

The eight transducers, two per separation group, make up four RCS flowmeters. Each transducer pair makes up one RCS flowmeter. The transducers are located below the steam generators, and above the RPV flange. They are in the proximity of the RCS T_{cold} 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.

6.1.3.3 Installation

The baseline reactor coolant flowmeter concept requires the mounting of ultrasonic flowmeter transducers into a {{

}}2(c), ECI

6.1.3.4 Maintenance

To insure 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, via access to the side of the vessel, should that be necessary.

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

6.1.3.5 Qualification

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}}2(c), ECI 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

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}}2(c)

5. {{

}}2(c)

7.0 Level Measurement in the NPM

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}}2(c) Other constraints that existed with the differential pressure method were: reference leg temperature compensation, condensate pot cooling during a DBA environment, and finding a delta-pressure cell that could survive and operate in the containment environment. The Phase 1 study looked for methods that would measure containment water level, pressurizer level, and RPV riser water 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.

From the various radar level measurement options, {{ }}2(c) measurement is the concept that best fits the NuScale design, although investigations into guided wave radar are ongoing as a back-up approach.

{{

}}2(c) models indicates that lengths to accommodate the NuScale application are achievable. NuScale plans to conduct tests to select the appropriate method and vendor for the development of custom level sensing devices for the NuScale design.

There are three NPM related level measurements. The first two, pressurizer level/RPV riser level and containment water level are baselined as {{ }}2(c) technology sensors. The third measurement, DHRS level, is baselined as a level switch technology and is located on the DHRS unit on the DHRS piping.

Table 7-1 Pressurizer/RPV/CNV water level

Level Transmitters	Range	Quantity	Function	Location	Safety/Risk Classification
Pressurizer level/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 Core cooling indication 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 – ECCS actuation 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 Binary	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/RPV riser level sensor is to provide 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. In its NSSS control function, pressurizer level is maintained within an operating band by the CVCS makeup and the letdown functions.

The pressurizer level/RPV riser level functions are implemented in a separate safety function module within each separation group. The level indications are also isolated to perform their control functions. The pressurizer level/RPV riser level functions are listed below.

Pressurizer level measurement functions:

- reactor trip - pressurizer level high

- reactor trip - pressurizer level low
- ESFAS – containment isolation - pressurizer level low-low
- ESFAS – DHRS actuation – pressurizer level low-low
- ESFAS – CVCS isolation – pressurizer level high and low-low
- ESFAS – pressurizer heater isolation – pressurizer level low
- core cooling indication
- NSSS controls
- MCR indication
- plant historian

RPV Riser Level Measurement Functions:

- ESFAS – ECCS actuation - RPV riser level low
- PAM Type B, C, and D variables
- core cooling Indication
- MCR indication
- plant historian

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(c)] percent of calibrated span

Sensor response time: $\leq$ 2 seconds

Quantity: Four, one for each separation group

7.1.3 Baseline Concept

7.1.3.1 Summary

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}}2(c), ECI

The NuScale diversity and defense in depth analysis for the MPS, specifies that different design organizations are required for equipment diversity in defense of CCF for the radar level measurement. This requirement likely manifests itself in the selection of two different vendors for the radar level measurement function.

7.1.3.2 Location

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}}2(c), ECI

7.1.3.3 Installation

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}}2(c)

7.1.3.4 Maintenance

Sensor calibration and maintenance are conducted at the processing electronics cabinet during a refueling outage. The sensor assembly, in the guide tube, should not need to be accessed for calibration activities. The development of this calibration methodology is itemized in the Future Work section below.

7.1.3.5 Qualification

Qualification of {{

}}2(c)

{{

}}2(c) sensor meets the specified qualification requirements.

7.1.4 Future Work

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}}2(c)

7.2 Containment Water Level

7.2.1 Sensor Functions

The primary function of the containment water level sensors is to provide an ESFAS actuation for safety system purposes. It is intended to protect the core by activating the ECCS to allow recirculation of RCS water inventory in containment and into the RPV. It also provides the necessary control room alarms/indications, and inputs to NSSS controls.

Containment water level measurement functions:

- ESFAS – ECCS actuation – high CNV water level
- ESFAS – L-1 interlock
- PAM Type B, C, and D variables
- core cooling indication
- MCR indication
- NSSS controls (containment flooding/containment evacuation)
- plant historian

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: ± {{ }}$^{2(c)}$ percent of calibrated span

Sensor response time: $\leq$ 2 seconds

Quantity: Four, one for each separation group

7.2.3 Baseline Concept

7.2.3.1 Summary

The baseline concept calls for a {{

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

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}}2(c)

The NuScale diversity and defense in depth analysis for the MPS, specifies that different design organizations are required for equipment diversity in defense of CCF for the radar level measurement. This requirement likely manifests itself in the selection of two different vendors for the radar level measurement function.

7.2.3.2 Location

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7.2.3.3 Installation

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}}2(c)

7.2.3.4 Maintenance

Sensor calibration is conducted at the processing electronics cabinet during a refueling outage. The sensor assembly, in the guide tube, should not need to be accessed for calibration activities. The development of this calibration methodology and periodic maintenance is itemized in the Future Work section.

7.2.3.5 Qualification

See Section 7.1.3.5 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 DHRS binary (yes/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 an operable level of condensable gases.

DHRS level measurement functions:

- MCR indication
- plant historian

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, two DHRS units

7.3.3 Baseline Concept

7.3.3.1 Summary

The baseline concept for the DHRS level sensors is to use a level switch approach. The outside containment access for this sensor allows for accessible installation and access to the pipe for the inclusion of a level switch. Several manufacturers offer level switches that would function adequately for this application. The {{

}}2(c)

7.3.3.2 Location

The DHRS level switch is mounted on the DHRS pipe, near the outside top of containment, which runs to the DHRS heat exchanger.

7.3.3.3 Installation

The switch 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 signal are fed to the MCS for MCR indication.

7.3.3.4 Maintenance

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

7.3.3.5 Qualification

This level switch will be tested and capable to operate in the reactor pool, attached to the DHRS unit during normal conditions, where the pool temperature is approximately 100 degree Fahrenheit. Because there is no enclosure for the level switch, the switch will be tested and viable for every condition associated with that area of the reactor pool, including submergence.

7.3.4 Future Work

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}}$^{2(c)}$

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/or study.

The normal and post-accident containment operating environments of the NuScale reactor 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 vessel utilize existing technology. The RTD was selected in all cases, excluding the ICI instruments, due to its nuclear experience, accuracy, and robust design. The description of how the RTDs are incorporated into the design is captured in section 4 of this report.

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-sensing element, and as such, would not survive in the containment environment. This report covers the selection of the inside containment pressure transducer with outside containment remote electronics as the solution for pressure measurement for sensors residing in containment. The advantage of this transducer is that the electronics are not required to be in close proximity to the sensing element. This solution is being investigated with the intention of improving on existing devices.

Measuring RCS flow in the RPV {{

}}2(c), ECI

Level measurements in the CNV and the {{

}}2(c), ECI Other solutions were investigated and it became apparent that the technology that showed the most promise was {{

}}2(c)

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

}}2(c), ECI

The future work items associated with each sensor function outlines the remaining work to be done in that sensor area. {{

}}2(c)

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.”