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TERRAPOWER, LLC – FINAL SAFETY EVALUATION FOR NAT-8922 "REACTOR SEISMIC ISOLATION SYSTEM QUALIFICATION TOPICAL REPORT," REVISION 2 (EPID NO. L-2024-TOP-0005)

SPONSOR AND SUBMITTAL INFORMATION

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Brief Description of the Topical Report: TerraPower topical report (TR) NAT-8922, "Reactor Seismic Isolation System Qualification," Revision 2 provides a description of the methodology used to establish the design criteria and qualification requirements of the Natrium reactor seismic isolation system (SIS). The results of the U.S. Nuclear Regulatory Commission (NRC) staff's review of Section 7 of this TR are summarized in the following sections of this safety evaluation (SE).

On April 18, 2024 (ML24101A195), the NRC staff informed TerraPower that the TR provided sufficient information for the NRC staff to begin its detailed technical review. On October 22, 2024, the NRC staff issued an audit plan to TerraPower (ML24297A136) and subsequently conducted an audit of materials related to the TR from November 8, 2024, to June 11, 2025. On June 30, 2025, the NRC staff issued the audit summary (ML25202A050). On July 10, 2025, TerraPower submitted a revision of the TR (ML25195A156), which superseded the prior submission.

In TR section 1, "Purpose," TerraPower requested NRC staff approval only for TR section 7 "Reactor Seismic Isolation System Design and Qualification Methodology." The NRC staff's evaluation is correspondingly limited to TR section 7, but the remaining information in the TR was considered to provide understanding and context for the application of the methodology.

For background, TerraPower's overall licensing approach for applications related to the proposed Natrium reactor design follows the Licensing Modernization Project (LMP) methodology described in Nuclear Energy Institute (NEI) 18-04, Revision 1, "Risk-Informed Performance-Based Technology Inclusive Guidance for Non-Light Water Reactor Licensing Basis Development" (ML19241A472). Regulatory Guide (RG) 1.233, "Guidance for a

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Technology-Inclusive, Risk-Informed, and Performance-Based Methodology to Inform the Licensing Basis and Content of Applications for Licenses, Certifications, and Approvals for Non-Light-Water Reactors," Revision 0 (ML20091L698) endorses the LMP methodology described in NEI 18-04, Revision 1.

REGULATORY EVALUATION

Title 10 of the *Code of Federal Regulations* (10 CFR) 50.34(a)(3)(i) requires construction permit (CP) applicants to include principal design criteria (PDC) as part of the preliminary safety analysis report for a proposed facility. As noted in 10 CFR 50.34(a)(3)(i), the General Design Criteria (GDC) in appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," establish the minimum requirements for the PDC for water-cooled nuclear power plants (NPPs) similar in design and location to plants for which CPs have previously been issued by the Commission. Further, 10 CFR 50.34(a)(3)(i) notes that the GDC provide guidance to CP applicants in establishing PDC for other types of nuclear power units, which would include the Natrium design. RG 1.232, "Guidance for Developing Principal Design Criteria for Non-Light-Water Reactors," (ML17325A611) describes the NRC staff's guidance on how the GDCs contained in 10 CFR Part 50 appendix A may be adapted for non-light water reactor (non-LWR) features.

The regulations in 10 CFR 50.34(a)(3)(i) require that facilities describe the PDC in their preliminary safety analysis report supporting a CP application.

Natrium PDC 1, "Quality standards and records," as described in NATD-LIC-RPRT-0002-A, "Principal Design Criteria for the Natrium Advanced Reactor," Revision 1 (ML24283A066) relates to the identification, evaluation, and documentation of codes and standards to determine their applicability, adequacy, and sufficiency. A quality assurance program shall be established and implemented in order to provide adequate assurance that structures, systems, and components (SSCs) will satisfactorily perform their safety functions.

Natrium PDC 2, "Design bases for protection against natural phenomena," as described in NATD-LIC-RPRT-0002-A, relates to design bases for protection against natural phenomena. PDC 2 requires that safety-significant SSCs shall be designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, floods, tsunami, and seiches without loss of capability to perform their safety functions.

Natrium PDC 80, "Reactor vessel and reactor system structural design basis," as described in NATD-LIC-RPRT-0002-A, relates to the reactor vessel and reactor system structural design basis. PDC 80 requires that the reactor vessel and reactor system be designed to maintain integrity during postulated accidents to ensure that passive heat removal can be maintained and that neutron absorbers can be inserted for reactor shutdown.

The regulations in 10 CFR 100.23, "Geologic and Seismic Siting Criteria" require, in part, that the geologic and seismic characteristics of the site and environs be investigated in sufficient scope and detail to permit an adequate evaluation of the proposed site; provide sufficient information to support estimates of the safe shutdown earthquake (SSE) ground motion; and permit adequate engineering solutions to actual or potential geologic and seismic effects at the site. RG 1.208, "A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion," Revision 0 (ML070310619), provides a methodology to comply with 10 CFR 100.23

using site-specific probabilistic seismic hazard analysis and developing Ground Motion Response Spectrum (GMRS) as input to determining SSE.

The regulations in 10 CFR Part 50, Appendix S, “Earthquake Engineering Criteria for Nuclear Power Plants” are applicable to applications, in part, for a CP or operating license (OL) pursuant to 10 CFR Part 50 on or after January 10, 1997. Appendix S requires that for SSE ground motions, certain SSCs will remain functional and within applicable stress, strain, and deformation limits. The required safety functions of these SSCs must be assured during and after the vibratory ground motion through design, testing, or qualification methods. The evaluation must consider soil structure interaction effects and the expected duration of the vibratory motion.

RG 1.233 provides guidance on using a technology-inclusive, risk-informed, and performance-based methodology to inform the licensing basis and content of applications for non-LWRs. RG 1.233 endorsed NEI 18-04, Revision 1.

RG 1.87, Revision 2, “Acceptability of ASME Code, Section III, Division 5, ‘High Temperature Reactors’,” (ML22101A233) describes an approach that is acceptable to assure the mechanical/structural integrity of components that, in part, operate in elevated temperature environments. It endorses, with exceptions and limitations, the 2017 Edition of the American Society of Mechanical Engineer (ASME) Boiler and Pressure Vessel Code (BPVC), Section III, “Rules for Construction of Nuclear Facility Components,” Division 5, “High Temperature Reactors.”

RG 1.100, Revision 4, “Seismic Qualification of Electrical and Active Mechanical Equipment and Functional Qualification of Active Mechanical Equipment for Nuclear Power Plants,” (ML19312C677) describes methods that the staff considers acceptable for use in the seismic qualification of electrical and active mechanical equipment and the functional qualification of active mechanical equipment for NPPs. It endorses, with exceptions and clarifications, the 2017 Edition of ASME Qualification of Mechanical Equipment (QME)-1-2017 “Qualification of Active Mechanical Equipment Used in Nuclear Facilities” for functional qualification of active mechanical equipment.

RG 1.246, Revision 0, “Acceptability of ASME Code, Section XI, Division 2, ‘Requirements for Reliability and Integrity Management (RIM) Programs for Nuclear Power Plants,’ For Non-Light Water Reactors,” (ML22061A244) describes an approach that is acceptable to the staff for the development and implementation of a preservice and inservice inspection program for non-LWRs. It endorses, with conditions, the 2019 Edition of ASME BPVC, Section XI, “Rules for Inservice Inspection of Nuclear Power Plant Components,” Division 2, “Requirements for Reliability and Integrity Management (RIM) Programs for Nuclear Power Plants.”

NUREG/CR-7253, “Technical Considerations for Seismic Isolation of Nuclear Facilities,” (ML19050A422), provides a set of technical considerations, recommendations, and options that could serve as the basis for regulation and regulatory review of the design, construction, and operation of seismic-isolated NPPs. The report presents a risk-informed and performance-based design philosophy for seismic isolation (SI) that was intended to be consistent with the NRC’s objectives and criteria approaches at the time of publication. Although the current TerraPower application differs in some regards from the situation considered in NUREG/CR-7253, the technical information in NUREG/CR-7253 remains applicable, as discussed in Section 3.3 of this SE.

The use of seismic isolation for safety related (SR) SSCs is not prevalent in commercial U.S. NPPs; however, the NRC seismic regulations do not preclude the use of seismic isolation[1]. American Society of Civil Engineers (ASCE)/Structural Engineering Institute (SEI) 43-19[2] and ASCE/SEI 4-16[3] are the two industry standards that address the analysis, design, construction, testing, inspection, and aging management requirements for SI. ASCE/SEI 43-19 incorporates the recommended performance criteria discussed in NUREG/CR-7253. The ASCE standards and NUREG/CR-7253 are primarily written for base-isolated structures rather than isolated components within a structure. The SIS proposed in this TR isolates the reactor enclosure system that is housed in the SR reactor building (RXB). The TR SIS technology is also 3-D compared to the 2-D systems discussed in NUREG/CR-7253 and ASCE/SEI 43-19. In the TR, TerraPower addresses these differences. For its review of the TR, the NRC staff considered applicable portions of NUREG/CR-7253 and ASCE/SEI 43-19 to evaluate the adequacy of TerraPower's proposed methodology.

TECHNICAL EVALUATION

1. INTRODUCTION

The subject TR provides the description of TerraPower's methodology to establish the design criteria and qualification requirements of the Natrium reactor SIS. The purpose of the TR is to obtain approval of the SIS design and qualification methodology by the NRC based on the NRC staff's review. Specifically, approval is sought for the use of the reactor SIS design and qualification methodology described in section 7 of the TR as an acceptable way of meeting requirements imposed by PDC 1, 2, and 80 for the SIS. The NRC staff have added limitation and condition 1, described later in this SE, limiting use of this SE to the content in Section 7 of the TR. Any licensee or applicant referencing this TR must evaluate the remaining six sections of the TR for the site-specific application.

Section 7 of the TR is divided into eight subsections that cover various aspects of the methodology. Section 7.1, "Risk-Informed Performance Based Seismic Design and Classification," describes the Design Basis Hazard Level for Natrium, which is established as the SSE, using guidance from RG 1.208 and the graded seismic classifications and associated design requirements for SSCs developed under NEI 18-04. Section 7.2, "Reactor Seismic Isolation System Industry Standards" describes the various American Society of Mechanical Engineer (ASME) codes and standards and their references in existing NRC guidance documents. Section 7.3, "Commentary on Seismic Isolation NRC Reports," provides a discussion on the information provided in NUREG/CR-7253, NUREG/CR-7254, "Seismic Isolation of Nuclear Power Plants Using Sliding Bearings," (ML19158A513), and NUREG/CR-7255, "Seismic Isolation of Nuclear Power Plants using Elastomeric Bearings," (ML19063A541) to determine whether the technical information in these documents was applicable to the Natrium

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[1] In 2022, the NRC staff published a pre-decisional draft RG, DG 1307 (ML22276A154), for SI titled, "Seismically Isolated Nuclear Power Plants," that utilizes the provisions of ASCE/SEI 43-19 and ASCE/SEI 4-16 standards with some clarifications, exceptions, and additions. A revised version of this draft RG is currently under review within the NRC at the time of issuance of this SE.
[2] ASCE/SEI 43-19, "Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities," ASCE, 2021.
[3] ASCE/SEI 4-16, "Seismic Analysis of Safety-Related Nuclear Structures," ASCE, 2017.

SIS system. Section 7.4, “Reactor Seismic Isolation System Requirement Allocation,” describes the performance criteria that the three-dimensional (3D) SIS must meet to provide assurance of acceptable performance. Section 7.5, “Reactor Seismic Isolation System Design and Analysis Methods,” describes the key dynamic characteristics, including the stiffness and damping, that are tuned by analysis and validated by testing to meet the SIS functional and performance requirements. Section 7.6, “Reactor Seismic Isolation System Design and Construction,” describes the specific ASME activities applicable during the construction of the SIS and the required ASME certificates of authorization. Section 7.7, “Reactor Seismic Isolation System Qualification,” describes the qualification program considering the specific characteristics of both the isolation spring unit (ISU) and the isolation damper unit (IDU). Section 7.8, “Reactor Seismic Isolation System Lifetime Management,” describes the Reliability and Integrity Management (RIM) program, which is established to assure reliability and integrity of the passive components of the SIS. The RIM program involves design interaction, performance monitoring, inspections, tests, maintenance, and replacements, to ensure the SIS SSCs achieve an acceptable level of reliability to support the seismic probabilistic risk assessment (SPRA) of the plant.

2. BACKGROUND

In this TR, TerraPower describes the methodology used to establish design criteria and qualification requirements of the Natrium reactor SIS for NRC review and approval. TerraPower specifically sought NRC approval only for section 7, including all subsections 7.1 to 7.8.

The NRC staff considered the information in the remaining sections of the TR, in addition to section 7, and provided audit questions and held audit discussions with TerraPower to get complete information on the design and qualification methodology of SIS to develop the basis for approval of section 7. However, the NRC staff evaluation is limited to section 7 of the TR, as requested by TerraPower. Section 3, “NRC Staff Evaluation,” of the SE contains the NRC staff evaluation. The subsections of section 3 of this SE map directly to the TR subsections of section 7.

2.1 Natrium Reactor Description

TerraPower provided an overview of the Natrium reactor in section 5.1, “Natrium Plant Description,” of the TR. The reactor system, which is a pool-type molten sodium cooled reactor, is contained in the reactor enclosure system (RES) and located in the RXB substructure. The below grade RXB is a reinforced concrete and steel substructure consisting of the head access area (HAA) and a cylindrical cavity. The RES is located within the RXB’s cylindrical cavity and is seismically isolated from the RXB substructure by the SIS. The RES consists of a reactor vessel and head, reactor internal structures, primary sodium coolant, and essential equipment required for coolant circulation and reactor heat rejection. The reactor support structure (RSS) provides a load path from the reactor vessel head to the RXB substructure. The RSS includes the modular isolated reactor support structure (MIRSS), reactor support block (RSB), and the SIS. The MIRSS and RSB form a stiff structure around the reactor head and the SIS is attached to the MIRSS and HAA reinforced concrete basemat creating an isolation interface between the RES and RXB.

TerraPower’s description of the Natrium reactor in the TR, and through audit discussions with the NRC staff, provided an overall understanding of the reactor system configuration and its location within the RXB, including the system and subsystem that TerraPower aims to use to seismically isolate the RES from the RXB. This description was sufficient to allow the NRC staff to complete its review. The NRC staff have added limitation and condition 2, limiting use of this methodology to the Natrium design, as summarized in sections 5.1 and 6 of the TR, or justify that any departures from these design features do not affect the conclusions of the TR and this SE.

2.2 Technical Reports

TerraPower provided a summary of the available technical reports related to the implementation of seismic isolation for nuclear facilities. There are three technical reports prepared for the NRC that discuss information that could be used to support potential technical guidance and considerations for seismic isolation of NPPs. The three reports are NUREG/CR-7253; NUREG/CR-7254; and NUREG/CR-7255.

2.3 Regulatory Precedence

TerraPower noted that the only regulatory precedence for application of seismic isolation of a nuclear reactor in the U.S. is the SE for the Kairos Power, LLC (Kairos), Hermes Test Reactor CP (ML23158A268). In the Kairos SE, the NRC staff approved the CP authorization without details of the isolation system based on the use of a consensus code (ASCE/SEI 43-19) and the identification of specific information to be provided at the operating license stage. This provides limited precedence due to the minimal level of information provided and reviewed at the CP stage and the difference in design approaches (i.e., base isolation versus system isolation and the use of ASCE/SEI 43-19).

2.4 Basis for Performance Criteria Adaptation

TerraPower proposed an SIS for the Natrium reactor using 3D equipment isolation (as discussed further in section 2.5, “Natrium Reactor SIS,” of this SE) and discussed some of the considerations of equipment isolation, in contrast with the two-dimensional base isolation systems typically used for building isolation. Although TerraPower stated in TR section 5.4 that it recognizes that the underlying seismic performance criteria recommended in NUREG/CR-7253 rely on discrete design requirements for design basis and beyond design basis earthquakes, TerraPower also stated that it recognizes that the evaluation needs to include risk and performance analyses consistent with the approach in the LMP as endorsed by RG 1.233.

TerraPower also noted in TR section 5.4 that there is no precedent for 3D equipment isolation, and points to the need for the TR to address design and qualification methodology for 3D component isolation.

2.5 Natrium Reactor SIS

The Natrium reactor SIS is discussed in section 6, “Natrium Reactor Seismic Isolation System,” of the TR. The RES is the primary system isolated by TerraPower’s proposed SIS. The reactor vessel and head of the RES contain the reactor core system and reactor internal structures and include coolant circulation and reactor heat rejection equipment. The RES also includes a guard vessel for mitigating potential sodium leakage and the support structure RSS. The TR lists the specific plant equipment that is isolated from the RXB by the SIS, which includes the RES and RES internals, equipment attached to or supported by the RES, and RES umbilicals. The equipment attached to or supported by the RES includes the reactor core system, the control rod drive system, the primary heat transport system (including intermediate heat exchangers and primary sodium pumps), the collector cylinder for the reactor air cooling system, certain components of the sodium cover gas system, and the in-vessel fuel handling system. The RES umbilical lines include piping for the intermediate heat transport system, the sodium cover gas system and sodium processing system, and instruments and cabling for the reactor instrumentation system.

TerraPower characterized the reactor SIS as 3D equipment isolation and stated that the typical range of isolation frequency for equipment is 1-4 Hz. TerraPower stated that the SIS consists of ISUs and IDUs alternately placed in a circular pattern within the RSS between the stiff MIRSS and HAA base slab, the ISU consists of multiple helical wire springs between two parallel mounting plates, and the IDU is a viscoelastic damper consisting of a damper housing containing viscous damper fluid and a piston immersed in the fluid. TerraPower stated that the IDU damps the seismic motion in all three directions and that the ISUs and IDUs supporting the RES will be designed (sized and calibrated) to adequately isolate ground motions from the RXB. TerraPower stated that stiffness characteristics of the ISUs reduce the frequency of the system to the required fundamental frequency of the reactor vessel and the internals, and the damping characteristics of the IDUs limit the displacement and reduce seismic demand on the RES. TerraPower stated in section 7.7 that ISUs are rigidly attached to the RSS and RXB.

TerraPower's description in section 6 provided the NRC staff with an overall understanding of the Natrium reactor SIS configuration and its location within the RXB. This description was sufficient to allow the NRC staff to complete its review. The NRC staff imposes limitation and condition 3, limiting use of this methodology to the specific component 3D isolation system technology described.

3. NRC STAFF EVALUATION

In section 7, TerraPower discussed the design and qualification methodology for the ISUs and IDUs for reactor isolation from seismic ground motion. The overall process is divided into eight topical areas and discussed in eight subsections in the TR. The NRC staff evaluates each subsection as addressed below.

3.1 RIPB Seismic Design and Classification Process

TerraPower stated in section 7.1 that the seismic design and qualification of the Natrium reactor, including the SIS, is based on a RIPB approach in accordance with the methodology described in NEI 18-04. The overall approach to establish seismic design and classification of the SIS is shown in figure 7-1, "Seismic Isolation System risk informed performance-based design process," of the TR. The TerraPower approach includes an iterative process that starts with an initial safety and seismic classification to develop a preliminary design that would meet the corresponding seismic demand. The resulting preliminary design and fragilities are then incorporated into the SPRA, and if insufficient to meet risk objectives, the seismic design and the fragility of the SIS are updated until the risk objectives are met within the framework of the SPRA. The objective of the iterative process is to show that the results of the SPRA meet NEI 18-04 risk targets. The RIPB approach is used to establish seismic safety significance, seismic special treatment, and qualification requirements of the SIS components.

For seismic input, TerraPower stated that the methodology includes a probabilistic seismic hazard analysis based on a Senior Seismic Hazard Analysis Committee Level 3 hazard study, with a site-specific GMRS developed following guidance in RG 1.208. The GMRS is used to establish the SSE and develop the reference ground motion for SIS component design and qualification through soil structure interaction of the RXB substructure. These site-specific evaluations of hazards and performance-based design ground motions will be required by 10 CFR Part 100, "Reactor Site Criteria," at each site where the proposed SIS is used. Table 4-1 in NEI 18-04, "Summary of Special Treatments for SR and [Non-Safety Related with Special Treatment] SSCs," also refers to the siting requirements in 10 CFR Part 100 for the seismic design basis.

TerraPower states that the SIS will be designed with the requirements of this TR and can rely either on site-specific or generic qualification processes. For site-specific qualifications, seismic qualification is limited to the site and particular RXB, SIS, and supported subsystems design. For generic qualifications, a generic broad-band high amplitude spectra is developed to envelop the expected shaking at the interface between supporting structures and the SIS. This generic broad-band amplitude spectra envelops a wide range of potential sites. Seismic analyses are performed to establish SIS performance and demands consistent with generic conservative strong shaking. Qualification tests are performed to demonstrate the SIS performance meets the requirements of the TR when subjected to the demands generated by the generic ground motion. The design and qualification methodology proposed in this TR is independent of site-specific geotechnical properties and ground motion spectra. However, as stated in section 6.1 of the TR, seismic analyses need to be performed for any site to confirm that the site-specific motion is enveloped by the generic ground motion. For conditions in which site-specific ground motions are not enveloped by the bounding generic ground motion spectra, TerraPower discusses that new bounding motions must be generated and the qualification process must be repeated. The NRC staff imposes limitation and condition 4, requiring that new bounding motions be generated and the qualification process repeated if site-specific ground motions are not enveloped by the bounding generic ground motion spectra.

TerraPower identified the ISUs and IDUs as SSCs that are expected to be SR under the safety classification process of NEI 18-04 because the SIS is a significant contributor to the plant's overall seismic risk. As SR SSCs, the ISUs and IDUs are subject to PDCs 1-5, which apply to all safety-significant SSCs. In addition, the ISUs and IDUs play a significant role in meeting the requirements for PDC 80, "Reactor vessel and reactor system structural design basis," as they provide an important part of the SR load path for the reactor vessel. This TR provides methods that contribute to meeting requirements of PDCs 1, 2, and 80, which are related to quality assurance and design to withstand design basis seismic events.

The seismic classification for SIS components is SCS1, as defined by TerraPower in TR section 7.1.2, "Seismic Classifications and Seismic Special Treatments." SCS1 is the classification for seismic risk significant SR SSCs. The associated SR risk-significant special treatment requires that SSCs are designed to withstand the SSE ground motion and remain functional. In addition, TerraPower will apply the quality assurance requirements of 10 CFR Part 50 appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants" to the SIS through application of their Quality Assurance Program Description (QAPD) to meet PDC 1. The quality assurance portions of this methodology contribute to meeting the requirements of the QAPD and PDC 1.

Therefore, based on the information provided in the TR, and the understanding of TerraPower's design process as discussed during the audit, the NRC staff determines that the seismic isolation system RIPB seismic design and classification process is acceptable for the SIS because it is consistent with the guidance provided in NEI 18-04, as endorsed in RG 1.233, to ensure that the SSC classification and risk information is sufficient to assign appropriate PDCs, safety functions, and performance objectives.

3.2 Reactor SIS Industry Standards

TerraPower stated in section 7.2 of the TR that specific industry standards for the design, materials, fabrication, and testing are identified based on operating experience and prior precedence in nuclear applications. These codes and standards have been discussed in NUREGs and RGs with respect to their applicability for high and low temperature reactor supports at NPPs. Although there is limited precedence for licensing of seismic isolation of nuclear reactors in the U.S., appendix S to Part 50 does not preclude seismic isolation and is therefore applicable in this case. TerraPower discussed the codes and standards and the specific rules that apply for design, construction, qualification and monitoring of ISUs and IDUs in TR section 7.2 and depicted in figure 7-3, "Reactor Seismic Isolation System Design and Qualification Applicable Codes and Standards." Although TerraPower did not specifically identify ASCE 4-16 in figure 7-3, the design requirement given in 7.4.3.11 commits to meeting ASCE 4-16.

The following standards are identified by TerraPower in section 7.2:

- ASME BPVC Section III, "Rules for Construction of Nuclear Facility Components," Division 5, "High Temperature Reactors," 2017, as endorsed, with exceptions and limitations, by RG 1.87.
- ASME [BPVC] Section III, "Rules for Construction of Nuclear Facility Components," Division 1, Subsection NF "Supports," 2017, as incorporated by reference in 10 CFR 50.55a.
- ASME [BPVC] Section III, "Rules for Construction of Nuclear Facility Components," Division 1 [(ASME.BPVC.III.1)], Subsection NCA "General Requirements for Division 1 and Division 2," 2021, as incorporated by reference in 10 CFR 50.55a.
- ASME QME-1 "Qualification of Active Mechanical Equipment Used in Nuclear Facilities," 2023.
- ASME [BPVC], Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," Division 2, "Requirements for Reliability and Integrity Management (RIM) Programs for Nuclear Power Plants," 2019, as endorsed by RG 1.246.
- ASME NQA-1 "Quality Assurance Requirements for Nuclear Facility Applications," 2015, as incorporated by reference in 10 CFR 50.55a.

TerraPower used ASME.BPVC.III.5 for RES support design based on the permitted temperature limits in ASME.BPVC.III.5 Subsection HA, Subpart A, Table HAA-1130-1, and TerraPower concluded that provisions in Subsection HF, Subpart A, "Low Temperature Service" apply for SIS design. Therefore, in accordance with HFA-1110(b) and applicable exceptions in HFA-1110(g), requirements contained in ASME.BPVC.III.1 Subsection NF are considered for design and construction of SIS components as standard supports for the reactor. In accordance with HFA-1110(g) design, material, fabrication, examination, and certification in Subpart NF is applied to spring coils, compression springs end plates, and compression dynamic stops.

For qualification of the isolation system, the methodology in the TR refers to ASME QME-1 to provide criteria and procedures for qualification of mechanical equipment used in nuclear facilities. The ISUs and IDUs would be qualified as dynamic restraints and the qualification principals, specifications, and program would follow the rules in ASME QME-1 Section QDR (qualification of dynamic restraints) and mandatory requirements of QDR-I.

TerraPower would follow the RIM program in accordance with ASME BPVC Section XI, Division 2 to ensure that IDUs and ISUs perform as designed and the reliability is consistent with the assumptions in SPRA of the plant during the entire operating life of the power plant. The RIM program addresses design integration, in-service inspection, performance monitoring, and surveillance of the SI system.

Based on the information provided in the TR, and the understanding of TerraPower's use of industry standards as discussed during the audit, the NRC staff determines that the use of these standards are acceptable because (a) the list of ASME standards is appropriate for design, material, fabrication, testing, examination, qualification, and in-service maintenance for the SIS system; (b) ASME.BPVC.III.5 is endorsed in RG 1.87 as a method acceptable to the staff for the materials, design, construction, and testing of mechanical systems and components and their supports of high temperature reactors; (c) the NRC staff endorsed, with exceptions and clarifications, ASME QME-1 for functional qualification of mechanical equipment at NPPs in RG 1.100 and considers that section QDR provides an acceptable approach for qualification of dynamic restraints; and (e) the NRC staff endorsed the RIM program in RG 1.246 with positions and conditions for implementation of ASME BPVC section XI, division 2.

The NRC staff notes that it has not yet endorsed the 2023 Edition of ASME QME-1 referenced in this TR. However, the NRC staff has reviewed ASME QME-1-2023 and considers the ASME standard to be acceptable for use as part of this TR if implemented consistent with the regulatory positions specified in Revision 4 to RG 1.100.

3.3 TerraPower Commentary on Seismic Isolation NRC Reports

TerraPower considered NUREG/CR-7253 for technical information on the design requirements and performance criteria for the SIS. NUREG/CR-7253 is applicable for 2D seismic isolation for NPP buildings and provides technical information for consideration. TerraPower concluded that the technical considerations in NUREG/CR-7253 can be adapted as the basis for the evaluation of seismic performance for 3D equipment isolation system within the RIPB framework based on NEI 18-04 LMP approach. TR table 7-1, "Commentary on NUREG/CR-7253," presents TerraPower's evaluation of the technical considerations in NUREG/CR-7253 that are relevant and applicable for the design and qualification of the proposed 3D isolation system for the Natrium reactor. TerraPower identified the applicable technical areas in NUREG/CR-7253 by section number and categorized them as applicable, not applicable, and meets intent. Each technical consideration that TerraPower determined to be applicable or meets intent, it then mapped to the SIS design and qualification requirements in section 7.4 of the TR.

One item not addressed in section 7.4 is the operation consideration for additional seismic monitoring equipment. NUREG/CR-7253 recommends that additional seismic monitoring equipment be used to enable characterization of the effect of seismic isolation in terms of the response of the NPP and the transmission of earthquake demands to the SSCs. TR table 7-1 states that, "[t]he need for additional seismic monitoring equipment is evaluated on a case-by-case basis to be determined on implementation of the seismic isolation system." The NRC staff added limitation and condition 9, described later in this SE, requiring any licensee or applicant using this TR to provide a basis for the adequacy of seismic monitoring equipment for the site-specific application that addresses the unique considerations for seismically isolated systems and the recommendations provided in NUREG/CR-7253, including justification for the location of instrumentation relative to the location of the seismic isolators.

The NRC staff reviewed the detailed assessment TerraPower provided regarding the applicability of the technical information provided in NUREG/CR-7253. The technical specifications that TerraPower identified as applicable to the SIS are described and assessed in TR section 7.4. The NRC staff also reviewed and concludes that the details of the NUREG/CR-7254 and NUREG/CR-7255 are not applicable to the TerraPower SIS because these NUREGs are specific to technologies that are not used in the TerraPower SIS.

3.4 Reactor SIS Requirement Allocation

The NRC staff reviewed section 7.4 of the TR which describes the technical and programmatic requirements that the 3D SIS must meet to satisfy performance criteria. These include design constraints, functional, performance, interface, and environmental requirements. TerraPower developed the design and qualification requirements for ISUs and IDUs considering safety classification of SIS, industry experience, and applicable codes and standards associated with the design and qualification of SIS components. The approach to verify the requirements for compliance, as discussed in the TR, is based on analysis, inspection, demonstration, acceptance testing, and qualification testing. The NRC staff also reviewed TR table 7-1, which presents a crosswalk between the technical considerations in NUREG/CR-7253 and relevant and applicable requirements in section 7.4 of the TR.

TerraPower’s SIS performance-based requirements are developed based on seismic classification, performance-based design approach, and performance envelope. As described in TR section 7.1, the SIS is seismic risk significant and classified as SR. TerraPower defined the design bases and design criteria of the SR SIS in table 7-2, “[SIS] Anticipated Seismic Special Treatment Category and Seismic Special Treatments.” The SIS would be designed for SSE ground motion and in accordance with applicable regulatory requirements of 10 CFR Part 100.23 and appendix S to 10 CFR Part 50, regulatory guidance, and codes and standards. TerraPower stated that the special treatment presented in table 7-2 of the TR stipulates (a) no damage to the SIS under SSE shaking, (b) the SIS is free to displace unobstructed to a maximum distance defined by the seismic target performance goal, and (c) the SIS retains its gravity load capacity under required deformed conditions.

TerraPower’s performance-based design objectives of the isolation system are based on tuning to the required isolation frequency of the SIS, spatial arrangement of ISU and IDUs, and ability to inspect the SIS. The vertical and horizontal stiffness of the ISUs placed in a circular pattern are balanced to control motions in three orthogonal directions including rocking motion of the RES. TerraPower stated in multiple instances in the TR that the SIS must maintain stability (i.e., ability to support vertical loads without excessive sustained lateral deformation). The properties of the IDUs are such that they do not support operational loads (the ISUs do), thus damage to the IDUs does not directly result in loss of stability.

TerraPower developed requirements for the performance envelope and qualification programs for the ISUs and IDUs. TerraPower based the performance expectations of the SIS on the licensing basis events (LBEs) within the LMP framework. As defined in table 7-3, “[SIS] performance expectations," of the TR, the response of the SIS for the anticipated operational occurrences and design-basis events should be essentially linear with no damage and for beyond-design basis events, the response of the SIS can be non-linear but damage should be limited. The testing requirements for ISUs and IDUs are discussed in section 7.4.1, "Seismic Isolation System risk-informed performance-based requirements allocation strategy," of the TR. Other specific technical and programmatic requirements, including their rationale, are documented under sections from 7.4.2 to 7.4.6 of the TR.

TerraPower's documented functional requirements in TR section 7.4.2, "Functional Requirements," include: providing isolation in three-dimensions; attenuation of seismic load during **[[**

]]. The functional requirements and rationale for the SIS, specified by TerraPower, are intended to provide adequate performance in case of an LBE consistent with the RIPB approach as outlined in NEI 18-04.

TerraPower's design constraints and quality requirements in section 7.4.3, "Design Constraint and Quality Requirements," of the TR include codes and standards for construction, qualification, RIM, quality assurance, fabrication installation, and compression spring end plate and compression dynamic stop design. The NRC staff reviewed the codes and standards in section 3.2 of this SE and determined they were acceptable for use in this TR. In addition, TerraPower identified that American Institute of Steel Construction N690[4] and American Concrete Institute 349[5] are associated with the structural design. TerraPower design requirements include developing SIS parameters based on analysis of the SIS and support components. The SIS analysis methods are required to conform to ASCE/SEI 4-16 based on design requirement 7.4.3.11 of TerraPower's methodology. The design constraints and quality requirements are adequately identified and provide performance-based requirements consistent with an RIPB approach.

TerraPower listed performance requirements for the SIS that include requirements for reliability and redundancy, displacement, testing, and long-term performance. TerraPower's performance requirements are documented in section 7.4.4, "Performance Requirements," and they address: reliability of the SIS to withstand SSE motion without damage; seismic isolation redundancy **[[**

]]. TerraPower established requirements for ISU and IDU testing to meet performance expectations in table 7-2 and 7-3 of the TR, which include **[[**

]]. Additional requirements include an evaluation of long-term performance of the SIS **[[**

]]. The NRC staff reviewed the SIS performance requirements proposed by TerraPower and the NRC staff concludes that they are adequate for

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[4] American Institute of Steel Construction, "Specification for Safety-Related Steel Structures for Nuclear Facilities, AISC N690-18," 2018.

[5] American Concrete Institute, "Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary, ACI 349-13," 2014.

demonstrating performance during LBEs, because they are in alignment with the RIPB concepts in NEI 18-04, as endorsed by RG 1.233. The NRC staff have added limitation and condition 5, described later in this SE, limiting the use of conclusions in this SE to designs that do not include a dynamic stop. If impact between the IDU piston and housing under extreme earthquake loading is deemed possible, then a sensitivity analysis should be conducted to bound the impact loads and response of critical SIS supported SSCs to determine the potential risks.

The requirements under environmental conditions discussed in section 7.4.5, “Environmental Requirements,” of the TR are (a) the SIS is protected from external hazards (e.g., fire, wind, flood) and (b) the SIS design includes the consideration of degradation from aging, creep, operating temperature, radiation, and moisture. The NRC staff reviewed the SIS environmental requirements documented by TerraPower and the NRC staff concludes that they adequately consider the environmental conditions through the application of appropriate codes and standards and are acceptable to the NRC staff.

The interface requirements of the SIS are identified in section 7.4.6, “Interface Requirements,” of the TR and include design of interfacing support structures, clearance between isolated and non-isolated structures, and adequate displacement of umbilical lines. TerraPower identified ACI 349 appendix D, “Anchoring to Concrete,” for anchorage design of SIS with RXB concrete base mat and bolting of SIS to steel components will be designed in accordance with ASME.BPVC III.1, subsection NF. The NRC staff reviewed the interface requirements and concluded that they are adequately described in the TR and that they address the considerations identified in NUREG/CR-7253 and ASCE/SEI 4-16. In table 7-1 of the TR, TerraPower committed to satisfying the intent of the peer review described in NUREG/CR-7253.

Based on the information provided in the TR on the performance-based requirements and the addition of the design verification and peer review requirement, the NRC staff determines the requirements identified for functional, design constraints and quality, performance, environmental and interface requirements to be acceptable because the requirements are consistent with: (a) the purpose of the seismic regulations of 10 CFR 100.23 and appendix S to 10 CFR Part 50; (b) RIPB methodology in NEI 18-04 and RG 1.233 for seismic classification and special treatment, and performance criteria; (c) acceptable codes and standards for design, construction, qualification, testing, and installation; and (d) the intent of NUREG/CR-7253 and ASCE/SEI 4-16 for modeling and analysis methodology, developing performance-based design approach, performance-based testing envelope, and criteria including considerations for construction, operation and monitoring. Any applicant using this methodology for SIS design should meet all the requirements identified in section 7.4 of the TR and demonstrate how it addresses the requirements in the license application.

3.5 Reactor SIS Design and Analysis Methods

In section 7.5 of the TR, TerraPower discussed the seismic analysis methodology for the design of the SIS to meet expected performance under seismic loads. The TR does not describe the details of the methodology, such as detailed provisions of specific codes and standards, but provides an approach to be used for the analysis of the reactor SIS. An applicant using TR SIS technology will have to implement the overall analysis approach described in this section with details showing how the pertinent regulations, regulatory guidance, and applicable codes and standards are met at the implementation level. The NRC staff have added limitation and condition 8, described later in this SE, requiring that applicants or licensees referencing this TR use the specific codes and standards listed in TR section 7. Any deviations from these codes and standards should be justified.

By using the analysis approach, TerraPower stated the key dynamic parameters of SIS stiffness and damping are tuned to balance between (a) limiting the displacements in three orthogonal directions and the rotations of the isolated system, (b) required isolation frequency range, and (c) attenuation of accelerations for isolated components. TerraPower stated that the displacement capacity of the SIS will be sufficiently large to accommodate the range of deflection while maintaining structural integrity and stability and that the optimized dynamic parameters of the SIS will be validated by qualification testing to meet functional and performance requirements discussed in section 7.4 of the TR. TerraPower describes two optional numerical modeling approaches: single-step and multi-step. TerraPower discussed approaches to account for variability of SIS properties and demand parameters in section 7.5.3 of the TR for both methodologies.

3.5.1 Single-step Numerical Modeling Approach

In a single-step approach, TerraPower proposes to represent the RXB, SIS, and the isolated systems in a single numerical model. The analysis will include the effects of soil-structure interaction and develop both the dynamic response of the SIS and the demand on the reactor system components in a single-step. TerraPower states that this approach provides options for response spectra or time-domain analysis. The NRC staff reviewed the single-step approach and consideration of variability of mechanical properties of isolator and demand described in the TR and found that the single-step approach is consistent with ASCE/SEI 4-16 and, therefore, the NRC staff finds the approach acceptable. Since the use of seismic isolation for SR SSCs is limited in U.S. NPPs and because TerraPower's modeling approach relies on a complex series of numerical modeling and the use of several modeling codes, the NRC staff is including limitation and conditions 6 and 7. These conditions describe that the use of this methodology for a site-specific application should address: (a) verification and validation of numerical models capable of predicting results of dynamic testing of the prototype isolators consisting of linear springs and viscoelastic dampers, and (b) development of a validation plan for the response analysis (i.e., depending on whether the multi-step or single-step analysis is used), and a verification plan for the codes used in the multi-step or single-step response analysis.

3.5.2 Multi-step Numerical Modeling Approach

TerraPower's multi-step approach for the analysis of the SIS is based on structural response analysis of three de-coupled models such that the output from one model serves as the input to the next model. TerraPower's multi-step approach is illustrated in the process diagrams shown in figures 7-4, "Seismic Isolation System performance envelope," 7-5 , "Example of multi-step seismic analysis process," and 7-6, "Accounting for variability in SIS properties of demand on SIS supported Subsystems," of the TR. TerraPower's multi-step approach includes the RXB SSI model, RES Model including the SIS, and the RES subsystem model of the reactor core. TerraPower described the overall modeling process in five steps as follows.

In the first step, the RES subsystem is represented by a simplified dynamically equivalent model that is incorporated in the detailed RES model. TerraPower stated that the subsystem model is calibrated to represent the effective mass participating at the fundamental mode of vibration.

In the second step, the RES model consists of the reactor core within the RES subsystem model, core supports, and a representation of the SIS. The model accounts for fluid-structure interaction of the submerged components. TerraPower stated that a simplified representation of the RES model is incorporated in the RXB model and ensures that the translational and rotational motions are accurately represented in the detailed and simplified RES model.

In the third step, the soil-structure interaction analysis of the RXB structural model is performed following guidance in ASCE/SEI 4-16. The dynamic characteristics of the RES model and the RES subsystem model are included in the RXB structural model. The dynamic motions at the base of the SIS from the seismic analysis of the RXB model are used to develop in-structure response spectra (ISRS) as input motion for dynamic analysis of detailed RES model in the fourth step.

The fourth step of the multi-step approach yields translational and rotational motions of the RES model and generates dynamic motions for the fifth step. TerraPower stated that the in-structure motions at the base of the SIS are smoothed, broadened, and local valleys are filled consistent with guidance from RG 1.122 or ASME.BPVC.III.1 N-1226.3 to develop the ISRS, if the response spectrum method is used. Alternatively, if time-history analysis is used, TerraPower will use guidance from ASME.BPVC.III.1 N-1222.3.

In the fifth step, motions generated in the fourth step are used to develop seismic demands for the detailed model of the RES subsystem. TerraPower will develop ISRS for the RES subsystem model using the approach described in the fourth step and account for multiple support locations in accordance with ASME.BPVC.III.1 N-1227.

The NRC staff reviewed the information provided in the TR on the multi-step dynamic analysis and modeling approach for the SIS and isolated system. The NRC staff determines the approach to be acceptable, because the multi-step modeling approach aligns with existing NRC guidance and accepted codes and standards through the following components of TerraPower's methodology: (a) the approach described for multi-step analysis includes consideration of soil-structure interaction and the representation of subsystems is consistent with ASCE/SEI 4-16; (b) the consideration of variability of mechanical properties of isolator and demand parameters are consistent with ASCE/SEI 4-16; (c) the ISRS at the base of the SIS used in structural analysis of the isolated models are smoothed and broadened in accordance with RG 1.122 or ASME III.1 N-1226.3 if response spectrum is used, and ASME III.1 N-1222.3 when time-history analysis is conducted; and (d) ASME III.1 N-1227 is used for systems supported at multiple locations.

3.6 Reactor SIS Design and Construction

As discussed in section 7.6 of the TR, the design and construction approach for the SIS components as standard supports would be in accordance with ASME.BPVC.III.1, Subsection NF. The SIS reactor vessel support is a structural component, and the design and construction are governed by the requirements of ASME.BPVC.III.5. However, because the temperature of the SIS support is below the code limits, the low temperature rules apply. ASME.BPVC.III.5 HFA refers to the requirements contained in Subsection NF for design and construction. TerraPower summarized the ASME code rules for construction in TR figure 7-7, "ASME BPVC Section III Nuclear Facility Construction Activities," and includes design, procurement of material, fabrication, testing, examination, and installation. In addition, the N-type certificates required in accordance with ASME codes are discussed and presented in TR table 7-4, "ASME Issued N-Type Certificates and Scopes Necessary for SIS." Installation of the SIS shall be in accordance with ASME.BPVC.III NCA-1282 which describes those activities required to attach the SIS to the building structures and other reactor support structures.

The NRC staff reviewed the information in section 7.6 of the TR, including the summary table 7-4, and determines that the information is acceptable because ASME.BPVC.III provides a complete set of rules for construction (design, materials, fabrication, testing, examination, and installation) of the SIS. ASME.BPVC.III.5 has been endorsed, with exceptions and limitations, by RG 1.87.

3.7 Reactor SIS Qualification

TerraPower stated in section 7.7 that the SIS will be qualified in accordance with ASME QME-1 as active mechanical equipment because the ISUs and IDUs undergo mechanical movements to perform their required isolation function. TerraPower clarified during the audit that the SIS consists entirely of passive components and that the qualification process follows the applicable requirements in ASME QME-1 Section "QR-General Requirements" and "QDR-Qualification of Dynamic Restraint."

TerraPower illustrated the qualification principles and philosophy in figure 7-8, "Seismic isolation system qualification program development," of the TR. TerraPower uses these requirements to establish basic characteristics (e.g., force-displacement relationship, aging and degradation mechanisms). TerraPower states that it will use ASME QME-1 requirements QR-5200 to establish qualification approaches, QR-7000 for qualification methods, QR-6000 for qualification specifications, QR-8300 for a certified qualification plan, and QR-8400 and QR-8500 for qualification and application reports, respectively.

TerraPower stated that the qualification principles and specification requirements for the springs and viscoelastic dampers are given in ASME QME-1 Section QDR-4000. For the ISUs, TerraPower stated that they will use the requirements for components defined as gap restraints in ASME QME-1 Section QDR-4300. Therein, gap restraints are expected to behave as a non-linear system during initial loading and unloading, but once the gap is closed, the system behaves linearly. TerraPower's ISUs are springs that are rigidly attached to the building and the RES with linear behavior in tension and compression, therefore ISUs are considered to be similar to gap restraints in the code where there is no gap that must be closed. TerraPower stated that the applicable functional requirements for testing to obtain the spring rate, spring fatigue, and load rating are defined in ASME QME-1 Section QDR-4310. TerraPower stated that the deflections imposed on the ISUs due to static and dynamic loading for the required spring rate will be determined through modeling as discussed in section 7.5 of the TR. TerraPower stated that the manufacturers will establish the spring rates by means of testing and that the spring rates are defined in both horizontal and vertical directions and are validated for the full range of displacements.

TerraPower stated that the qualification requirements for viscoelastic dampers are provided in ASME QME-1 Section QDR-4400 and QDR-4410. TerraPower also stated that the functional parameters of the dampers that require qualification testing include drag, rated load, spring stiffness rate, damping resistance, and allowable displacement and that the stiffness and damping parameters are functions of damping fluid viscosity, which is temperature and radiation dependent; the rate and frequency of applied loading; and displacement.

TerraPower stated that the qualification specifications are based on ASME QME-1 Mandatory appendix QDR-I and that the minimum contents per QDR-I for the Natrium reactor SIS's qualification specifications are summarized in figure 7-9, "Qualification specification minimum content," of the TR. TerraPower stated that the qualification specifications for the SIS include Application Characteristics (QDR-I-5100), Design Requirements (QDR-I-5200), Operational Requirements (QDR-I-5300), Functional Parameters (QDR-I-5400), Special Material Requirements (QDR-I-5500), Installation and Orientation Requirements (QDR-I-5600), Maintenance, Examination, and Test Requirements (QDR-I-5700), and Special Performance Requirements (QDR-I-5800).

TerraPower will use two basic methods for the qualification program as described in section 7.7.2, "Qualification Program,": parent qualification and candidate qualification. TerraPower stated that parent qualification will be utilized for a Natrium licensing application if a previous qualification program is not available. TerraPower referred to the requirements in ASME QME-1 QDR-6200 for parent qualification. TerraPower's qualification plan for the SIS will specify the functional parameters and environmental variables subject to testing as established in the qualification specification. TerraPower stated that the specific elements considered during testing include installation and orientation, test and monitoring equipment, test sequence, functional parameter testing for ISUs, functional parameter testing for IDUs, aging and service condition simulation, special tests, material data requirements, limits of failure definition, and post-test examination and analysis.

TerraPower stated that candidate qualification of SIS for future plants that are identical (same manufacturer, type, size etc.) to a qualified Natrium parent SIS will follow requirements of QDR-7320. SIS that are not identical to the parent SIS may be qualified by extension through analysis and testing. TerraPower stated its candidate qualification process requires a high degree of similarity between the parent SIS and the candidate SIS, as evaluated in ASME QME-1 QDR-6300 and QDR-6320.

TerraPower's qualification documentation requirements are based on QDR-7000 as discussed in section 7.7.3 "Qualification Documentation Requirements," and they specify a qualification plan (QDR-7200), a qualification report (QDR-7310), and application report (QDR-7320). The latter two of these reports need to be certified by registered professional engineer in accordance with QR-8620 and QR-8630, as noted in TR section 7.7.3.

The NRC staff reviewed the SIS qualification approach and finds the information presented in TR section 7.7, including TR figure 7-8, is acceptable because (a) the NRC staff endorsed ASME QME-1 for functional qualification of mechanical equipment at NPPs in RG 1.100 and considers that Section QDR provides an acceptable approach for qualification of dynamic restraints; (b) it is consistent with the intent of NUREG/CR-7253 for developing a testing program for demonstrating adequate performance of the SIS components; (c) it is consistent with the requirements for qualification testing reviewed in section 3.4 of this report.

As noted earlier, the NRC staff has not yet endorsed the 2023 Edition of ASME QME-1 referenced in this TR. However, the NRC staff has reviewed ASME QME-1-2023 and considers the ASME standard to be acceptable for use as part of this TR if implemented consistent with the regulatory positions specified in Revision 4 to RG 1.100.

3.8 Reactor SIS Lifetime Management

TerraPower stated in TR section 7.8 that the reactor SIS is included within the ASME BPVC Section XI, Division 2 RIM program. TerraPower stated its RIM program addresses in-service inspection, monitoring and surveillance for the entire operating life of the plant and that development of the RIM program includes performing a degradation mechanism assessment of the SSCs within the program, establishing the reliability targets for the SSCs, and establishing the RIM strategies to ensure those reliability targets are met throughout the life of the SSCs. TerraPower stated it will implement the process described in section 7.8 for the life cycle management of the reactor SIS and that RIM strategies may include the use of monitoring, surveillance and/or inspections.

The NRC staff reviewed the RIM process described in section 7.8 and determines the use of ASME BPVC Section XI, Division 2 RIM program for life cycle management of the reactor SIS acceptable because (a) the RIM program provides a process to assess component degradation and implement appropriate strategies to ensure the component reliability and integrity are properly managed; and (b) the NRC staff has endorsed ASME BPVC Section XI, Division 2 RIM in RG 1.246 for the development and implementation of an in-service inspection program for non-light water reactors.

LIMITATIONS AND CONDITIONS

The NRC staff identified the following limitations and conditions applicable to any licensee or applicant referencing this TR:

1. The conclusions reached in this SE only address the content provided in section 7 of the TR. Thus, any licensee or applicant referencing this TR must evaluate the other aspects of the information described in the remaining six sections of the TR for any site-specific application.

2. An applicant or licensee referencing this TR must use the Natrium design, as summarized in sections 5.1 and 6 of the TR, or justify that any departures from these design features do not affect the conclusions of the TR and this SE.

3. The methodology described in the TR and the conclusions reached in this SE are based on a component 3D isolation system using ISUs and IDUs which limit displacement and are arranged to ensure an even distribution of loads within the SIS and limits the seismic demands exerted on the reactor. The details of the methodology in TR section 7 that were reviewed by the NRC staff are limited to this specific component 3D isolation technology.

4. If an applicant or licensee referencing this TR chooses to follow a generic qualification process as described in TR section 6.1, they must perform seismic analyses to confirm that the site-specific motion (based on the site and design of RXB, SIS, and supported subsystems) is enveloped by the generic ground motion. For conditions in which site-specific ground motion spectra are not enveloped by the bounding generic ground motion spectra, a new bounding spectra must be generated and the qualification process must be repeated.

5. The conclusions reached in this SE are limited to a design that does not include a dynamic stop. If impact between the IDU piston and housing under extreme earthquake loading is deemed possible, then a sensitivity analysis should be conducted to bound the impact loads and response of critical SIS supported SSCs to determine the potential risks.

6. The conclusions reached in this SE are based on TerraPower's methodology for verification and validation of numerical models capable of predicting results of dynamic testing of the prototype isolators consisting of linear springs and viscoelastic dampers. To use this methodology at a specific site, an applicant or licensee shall confirm that the range of applicability for the numerical models encompass the site-specific conditions.

7. The conclusions reached in this SE are based on TerraPower's multi-step or single-step methodology for plant seismic response analysis. To use this methodology at a specific site, an applicant or licensee shall develop a validation plan for the single-step or multi-step response analysis (including transitions between analysis codes), as applicable, and a verification plan for the codes used in the response analysis.

8. The conclusions reached in this SE are based on the specific codes and standards used to implement the methodology, listed in TR section 7. Applicants or licensees referencing this TR should justify any deviations to these codes and standards. An application using the TR methodology at any site requires a peer review as described in TR table 7-1.

9. Applicants or licensees referencing this TR must provide a basis for the adequacy of seismic monitoring equipment for the site-specific application that addresses the unique considerations for seismically isolated systems and the recommendations provided in NUREG/CR-7253, including justification for the location of instrumentation relative to the location of the seismic isolators.

CONCLUSION

The NRC staff has completed its review of Section 7 of the TR NAT-8922, "Reactor Seismic Isolation System Qualification Topical Report," Revision 2. The methodology described in this report is in the context of the Natrium design with specific SIS components and configuration. The TerraPower SIS specifically uses IDUs and ISUs. Based on its evaluation of the TR, the NRC staff determines that Section 7 of the TR, subject to the limitations and conditions discussed above, provides an acceptable methodology for the design and qualification of a 3D equipment SIS for the Natrium design. The methodology and qualification description in the TR are also consistent with the regulatory guidance and information available discussed in this SE. Accordingly, the NRC staff concludes that the SIS methodology and qualification described in Section 7 of this TR is acceptable for consideration at sites utilizing the Natrium design, as summarized in sections 5.1 and 6 of the TR. Therefore, based on the NRC staff's review, this TR provides a methodology that is acceptable for use in meeting requirements associated with PDC 1, 2, and 80 for the SIS.

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