

November 12, 2025

TP-LIC-LET-0463
Docket Number 50-613

U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
ATTN: Document Control Desk

Subject: Submittal of Approved TerraPower, LLC Reactor Seismic Isolation System Qualification Topical Report

References: 1. U.S. Nuclear Regulatory Commission, TerraPower, LLC – Final Safety Evaluation of NAT-8922, Reactor Seismic Isolation System Qualification Topical Report, Revision 2 (ML25296A227)

The U.S. Nuclear Regulatory Commission (NRC) provided the final safety evaluation for the TerraPower, LLC (TerraPower) Reactor Seismic Isolation System Qualification Topical Report in Reference 1. The topical report provides an overview and description of the seismic isolation system qualification methodology for the Natrium^{®1} Plant.

Enclosures 2 and 3 of this letter provide the accepted version of the topical report with additional content incorporated per NRC staff request, designated NAT-8922-A.

The report contains proprietary information and as such, it is requested that Enclosure 3 be withheld from public disclosure in accordance with 10 CFR 2.390, "Public inspections, exemptions, requests for withholding." An affidavit certifying the basis for the request to withhold Enclosure 3 from public disclosure is included as Enclosure 1. Proprietary materials have been redacted from the report provided in Enclosure 2; redacted information is identified using [[]]^{(a)(4)}.

¹ Natrium is a TerraPower and GE Vernova Hitachi Nuclear Energy Technology.



Date: November 12, 2025

Page 2 of 2

This letter and the associated enclosures make no new or revised regulatory commitments.

If you have any questions regarding this submittal, please contact Ian Gifford at igifford@terrapower.com.

Sincerely,

A handwritten signature in black ink that reads "George Wilson".

George Wilson
Senior Vice President, Regulatory Affairs
TerraPower, LLC

Enclosures: 1. TerraPower, LLC Affidavit and Request for Withholding from Public Disclosure (10 CFR 2.390(a)(4))
2. TerraPower, LLC Topical Report NAT-8922-A, Revision 2, Reactor Seismic Isolation System Qualification – Non-Proprietary (Public)
3. TerraPower, LLC Topical Report NAT-8922-A, Revision 2, Reactor Seismic Isolation System Qualification – Proprietary (Non-Public)

cc: Mallecia Sutton, NRC
Josh Borromeo, NRC
Nathan Howard, DOE

ENCLOSURE 1

**TerraPower, LLC Affidavit and Request for Withholding from Public Disclosure
(10 CFR 2.390(a)(4))**

Enclosure 1
TerraPower, LLC Affidavit and Request for Withholding from Public Disclosure
(10 CFR 2.390(a)(4))

I, George Wilson, hereby state:

1. I am the Senior Vice President, Regulatory Affairs and I have been authorized by TerraPower, LLC (TerraPower) to review information sought to be withheld from public disclosure in connection with the development, testing, licensing, and deployment of the Natrium[®] reactor and its associated fuel, structures, systems, and components, and to apply for its withholding from public disclosure on behalf of TerraPower.
2. The information sought to be withheld, in its entirety, is contained in Enclosure 3, which accompanies this Affidavit.
3. I am making this request for withholding, and executing this Affidavit as required by 10 CFR 2.390(b)(1).
4. I have personal knowledge of the criteria and procedures utilized by TerraPower in designating information as a trade secret, privileged, or as confidential commercial or financial information that would be protected from public disclosure under 10 CFR 2.390(a)(4).
5. The information contained in Enclosure 3 accompanying this Affidavit contains non-public details of the TerraPower regulatory and developmental strategies intended to support NRC staff review.
6. Pursuant to 10 CFR 2.390(b)(4), the following is furnished for consideration by the Commission in determining whether the information in Enclosure 3 should be withheld:
 - a. The information has been held in confidence by TerraPower.
 - b. The information is of a type customarily held in confidence by TerraPower and not customarily disclosed to the public. TerraPower has a rational basis for determining the types of information that it customarily holds in confidence and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The application and substance of that system constitute TerraPower policy and provide the rational basis required.
 - c. The information is being transmitted to the Commission in confidence and, under the provisions of 10 CFR 2.390, it is received in confidence by the Commission.
 - d. This information is not available in public sources.
 - e. TerraPower asserts that public disclosure of this non-public information is likely to cause substantial harm to the competitive position of TerraPower, because it would enhance the ability of competitors to provide similar products and services by reducing their expenditure of resources using similar project methods, equipment, testing approach, contractors, or licensing approaches.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on: November 12, 2025



George Wilson

Senior Vice President, Regulatory Affairs

TerraPower, LLC

ENCLOSURE 2

**TerraPower, LLC Topical Report
"Reactor Seismic Isolation System Qualification,"
NAT-8922-A, Revision 2**

Non-Proprietary (Public)



TerraPower, LLC
15800 Northup Way
Bellevue, WA 98008



A TerraPower & GE Vernova Hitachi Nuclear Energy Technology

Reactor Seismic Isolation System Qualification

NAT-8922-A

Revision 2

November 7, 2025



UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

October 24, 2025

George Wilson
Senior Vice President, Regulatory Affairs
TerraPower, LLC
15800 Northup Way
Bellevue, WA 98008

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

Dear George Wilson:

By letter dated March 8, 2024, TerraPower, LLC (TerraPower) submitted topical report (TR) NAT-8922, "Reactor Seismic Isolation System Qualification Topical Report," Revision 0 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML24068A212) to the U.S. Nuclear Regulatory Commission (NRC) staff. The TR provides an overview and description of the seismic isolation system qualification methodology for the Sodium reactor design. On April 17, 2024, the NRC staff found that the material presented in the TR provides technical information in sufficient detail to enable the NRC staff to conduct a detailed technical review (ML24101A200). 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 TR submission.

The enclosed final safety evaluation (SE) is being provided to TerraPower, because the NRC staff found NAT-8922, Revision 2, acceptable for referencing the licensing actions to the extent specified and under the limitations and conditions delineated in the TR. The final SE defines the basis for the NRC staff's acceptance of the TR.

The NRC staff requests that TerraPower publish an approved version of this TR within 3 months of receipt of this letter. The approved version should incorporate this letter and the enclosed SE after the title page. The approved version should include a "-A" (designating approved) following the TR identification symbol.

G. Wilson

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If you have any questions, please contact Stephanie Devlin-Gill at (301) 415-5301 or via email at Stephanie.Devlin-Gill@nrc.gov.

Sincerely,

/RA/

Joshua Borromeo, Chief
Advanced Reactor Licensing Branch 1
Division of Advanced Reactors and Non-Power
Production and Utilization Facilities
Office of Nuclear Reactor Regulation

Project No.: 99902100

Enclosure:
As stated

cc: TerraPower Natrium via GovDelivery

SUBJECT: TERRAPOWER, LLC – FINAL SAFETY EVALUATION FOR NAT-8922 "REACTOR SEISMIC ISOLATION SYSTEM QUALIFICATION TOPICAL REPORT," REVISION 2 (EPID NO. L-2024-TOP-0005) DATED: OCTOBER 24, 2025

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ADAMS Accession Nos.:**Pkg: ML25296A226****Letter: ML25296A227****Enclosure (Public): ML25296A229****Enclosure (Non-Public): ML25296A228**

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NAME	CdeMessieres (GObersen for)	SDevlin-Gill	DGreene
DATE	06/18/2025	10/23/2025	06/30/2025
OFFICE	NRR/DANU/UAL1:BC		
NAME	JBorromeo		
DATE	10/24/2025		

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

**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

Sponsor: TerraPower, LLC (TerraPower)

Sponsor Address: 15800 Northup Way, Bellevue, WA 98008

Project No.: 99902100

Submittal Dates: March 8, 2024, and July 10, 2025

Submittal Agencywide Documents Access and Management System (ADAMS) Accession Nos.: ML24068A212 and ML25195A156

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 Sodium 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 Sodium 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

Enclosure

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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 Sodium 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.

Sodium PDC 1, “Quality standards and records,” as described in NATD-LIC-RPRT-0002-A, “Principal Design Criteria for the Sodium 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.

Sodium 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, tsunamis, and seiches without loss of capability to perform their safety functions.

Sodium 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.

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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 isolation¹. American Society of Civil Engineers (ASCE)/Structural Engineering Institute (SEI) 43-19² and ASCE/SEI 4-16³ 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 Sodium 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 Sodium, 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 Sodium

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 Sodium 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 Sodium Reactor Description

TerraPower provided an overview of the Sodium reactor in section 5.1, "Sodium 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 Sodium 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

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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.

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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.

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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 Sodium 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]

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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 N690⁴ and American Concrete Institute 349⁵ 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

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 Sodium 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 Sodium 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 Sodium 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.

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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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NATRIUM

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REVISION HISTORY

Revision No.	Effective Date	Affected Section(s)	Description of Change(s)
0		All	Initial issue.
1	6/25/2025	1, 6, 7	<p>Implemented changes based on comments from the Nuclear Regulatory Commission audit. These include:</p> <ul style="list-style-type: none"> • Section 1: Added a sentence to indicate applicability of the report • Section 1: updated title of Sub-section 7.5 • Section 6.1 is new and added to address the applicability of the report. • Section 7.2 was updated to include additional details on the anchorage of the seismic isolation system. • Table 7-1 was updated to remove reference to RG 1.12. Comment b was supplemented with new information. • Figure 7-4 was removed along with references to this figure in the body of the report. • Requirements 7.4.2.2 and 7.4.2.3 were updated based on comments from audit performed by the Nuclear Regulatory Commission. • Requirement 7.4.4.13 was updated to correct a typo. • Section 7.5 and associated subsections were updated throughout to include additional information based on comments from audit performed by the Nuclear Regulatory Commission. • References: ASME QME-1 revision was updated to 2023 throughout the report. References to approval of QME-1 by RG 1.100 were removed. • References: unused references were removed. <p>Removal of proprietary markings in most sections of the report.</p>
2	7/8/2025	Header	The header line as of page 39 through the end of the document was updated.

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1 PURPOSE

The purpose of this report is to provide a description of the methodology and requirements to establish the design criteria and qualification of the SodiumTM reactor seismic isolation system (SIS) for review and approval by the U.S. Nuclear Regulatory Commission (NRC). The requirements in this report related to design and qualification methodology are independent of site-specific geotechnical properties and ground motion spectra.

Specifically, approval is sought for the use of the reactor SIS design and qualification methodology described in the following sections:

- Section 7: Reactor Seismic Isolation System Design and Qualification Methodology
 - Sub-section 7.1: Risk-Informed Performance Based Seismic Design and Classification Process
 - Sub-section 7.2: Reactor Seismic Isolation System Industry Standards
 - Sub-section 7.3: Commentary on Seismic Isolation NRC Reports
 - Sub-section 7.4: Reactor Seismic Isolation System Requirement Allocation
 - Sub-section 7.5: Reactor Seismic Isolation System Design and Analysis
 - Sub-section 7.6: Reactor Seismic Isolation System Design and Construction
 - Sub-section 7.7: Reactor Seismic Isolation System Qualification
 - Sub-section 7.8: Reactor Seismic Isolation System Lifetime Management

2 ASSUMPTIONS REQUIRING VERIFICATION AND OPEN ITEMS

There are no assumptions used in the development of this report requiring verification. There are no open items that require future actions to verify and close.

3 INPUTS

The inputs to this report to develop the methodology for design and qualification are comprised of industry technical reports, industry codes and standards, and applicable technical background information, and are referenced throughout this report.

4 TERMINOLOGY

Table 4-1 defines terms, acronyms and abbreviations used in this document.

Table 4-1. Terminology and Abbreviations

Term	Acronym / Abbreviation	Description Definition
Active Mechanical Equipment		Mechanical equipment containing moving parts, which, in order to accomplish its required function as defined in the Qualification Specification, must undergo or prevent mechanical movement. This includes any internal components or appurtenances whose failure degrades the required function of the equipment [1].
Aging		The cumulative effects of operational, environmental, and system conditions on equipment during a period of time up to, but not including, design-basis events or the process of simulating these effects [1].
American Concrete Institute	ACI	American Concrete Institute is a technical and educational society dedicated to improving the design, construction, maintenance, and repair of concrete structures and to advancing concrete knowledge by conducting seminars, managing certification programs, and publishing technical documents.
American Institute of Steel Construction	AISC	The American Institute of Steel Construction (AISC), headquartered in Chicago, is a not-for-profit technical institute and trade association established in 1921 to serve the structural steel design community and construction industry in the United States.
American Society of Civil Engineers	ASCE	The American Society of Civil Engineers (ASCE) is a not-for-profit membership organization whose mission is to facilitate the advancement of technology; encourage and provide the tools for lifelong learning; promote professionalism and the profession; develop and support civil engineers.
American Society of Mechanical Engineers	ASME	ASME is an American professional association that promotes the art, science, and practice of multidisciplinary engineering and allied sciences around the globe via continuing education, training and professional development, codes and standards, research, conferences and publications, government relations, and other forms of outreach.
Anticipated Operational Occurrence	AOO	Anticipated event sequences expected to occur one or more times during the life of a nuclear power plant, which may include one or more reactor modules. Event sequences with mean frequencies of 1×10^{-2} /plant-year and greater are

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Term	Acronym / Abbreviation	Description Definition
		classified as AOOs. AOOs take into account the expected response of all SSCs within the plant, regardless of safety classification [2].
Application Report		Documentation for a specific application showing that the required pressure ratings, qualification loading levels, and operating condition capabilities are equaled or exceeded by the corresponding pressure ratings, qualification loadings, and operating condition capabilities shown in the Qualification Report [1].
Authorized Inspection Agency	AIA	An organization that is empowered by an enforcement authority to provide inspection personnel and services [3].
Beyond-Design Basis Event	BDBE	Rare event sequences that are not expected to occur in the life of a nuclear power plant, which may include one or more reactor modules, but are less likely than a DBE. Event sequences with frequencies of 5×10^{-7} /plant-year to 1×10^{-4} /plant-year are classified as BDBEs. BDBEs take into account the expected response of all SSCs within the plant regardless of safety classification [2].
Boiler and Pressure Vessel Code	BPVC	
Candidate Equipment		Active mechanical equipment to be qualified in accordance with the rules of ASME QME-1 [1].
Candidate Restraint		Those components qualified through extension of parent qualification [1].
Component Supports		Structural elements that transmit loads between the components and building structure; intervening elements, such as electric motors and valve operators, are not included in the component support load path [1].
Construction Permit Application	CPA	
Core Barrel Structures	CBS	
Damping resistance		A linear approximation of the relationship of the load velocity characteristics of the viscoelastic damper piston [1].
Defense-in-Depth	DID	An approach to designing and operating nuclear facilities that prevents and mitigates accidents that release radiation or hazardous materials. The key is creating multiple independent and redundant layers of defense to compensate for potential human and mechanical failures so that no single layer, no matter how robust, is exclusively relied upon. Defense-in-depth includes the use of access controls, physical barriers, redundant and diverse key safety functions, and emergency response measures. [2].

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Term	Acronym / Abbreviation	Description Definition
Degradation mechanism		A phenomenon or process that attacks (e.g., wears, erodes, corrodes, cracks) the material under consideration [4].
Degradation Mechanism Assessment	DMA	Potential active degradation mechanisms for the SSCs within the RIM Program scope [4].
Degree-of-freedom	DOF	
Design Basis Accident	DBA	Postulated event sequences that are used to set design criteria and performance objectives for the design of Safety- Related SSCs. DBAs are derived from DBEs based on the capabilities and reliabilities of Safety-Related SSCs needed to mitigate and prevent event sequences, respectively. DBAs are derived from the DBEs by prescriptively assuming that only Safety-Related SSCs are available to mitigate postulated event sequence consequences to within the 10 CFR 50.34 dose limits [2].
Drag		The load required to maintain restraint movement at a specific velocity [1].
Dynamic Restraint		Any support that, by design, has a primary purpose of controlling dynamic movement of a pipe or component. Restraints may be single items or assemblies comprising multiple items [1].
Extreme Position		That limit on the piston position relative to the barrel of a viscoelastic damper where the specified damping or stiffness characteristics are no longer applicable [1].
Friction pendulum	FP	
Ground Motion Response Spectra	GMRS	Horizontal and Vertical site characterization response spectra developed from the UHRS in the free field on the ground surface or top of competent material (RG 1.208 [5]).
Guard Vessel	GV	
Inservice Inspection	ISI	Checks or inspections of safety performance functions and characteristics to ensure that any significant degradation is observed and timely corrective actions are taken.
International Atomic Energy Agency	IAEA	The IAEA is an independent intergovernmental, science and technology-based organization, in the United Nations family, that serves as the global focal point for nuclear cooperation.
Isolation damper unit	IDU	A viscoelastic damper unit used as a part of the seismic isolation assembly.
Isolation spring unit	ISU	Assembly of springs typically in parallel used as elastic foundation for seismic isolation.
Lead-rubber isolator	LR	
Light-water reactor	LWR	
Low-damping rubber isolator	LDR	
MANDE expert panel	MANDEEP	

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Term	Acronym / Abbreviation	Description Definition
Modular isolated reactor support structure	MIRSS	
Monitoring and NDE	MANDE	A term used in ASME BPVC.XI.2 [4] that encompasses the activities of monitoring, NDE, and surveillance specimen use, as established by the Monitoring and NDE Expert Panel (MANDEEP).
N-certificate holder		An organization holding a Certificate of Authorization, Certificate of Authorization (Corporate), or Quality Assurance Program Certificate issued by ASME. This does not include the holder of a Quality System Certificate or Owner's Certificate [3].
Non-destructive examination	NDE	An examination by the visual, surface, or volumetric method.
Nuclear power plant	NPP	
Nuclear regulatory commission	NRC	An independent agency of the United States government, the NRC regulates commercial nuclear power plants and other uses of nuclear materials, such as in nuclear medicine, through licensing, inspection, and enforcement of its requirements.
Owner	OWN	The organization legally responsible for the construction and/or operation of a nuclear facility including but not limited to the one who has applied for, or has been granted, a construction permit or operating license by the regulatory authority having lawful jurisdiction [3].
Parent Restraint		Components used to initially qualify a given design [1].
Pre-service inspection	PSI	
Pressurized water reactor	PWR	
Previously Qualified Restraint		An ASME BPVC restraint that was qualified to existing industry standards prior to Section QDR and that has an established performance history in similar safety-related applications [1].
Probabilistic risk assessment	PRA	A systematic method for assessing three questions used to define "risk." These questions consider (1) what can go wrong, (2) how likely it is to go wrong, and (3) what are the consequences. These questions allow better understanding of likely outcomes, sensitivities, areas of importance, system interactions, and areas of uncertainty which can identify risk-significant scenarios. The PRA is used to establish a numeric estimate of risk to provide insights into the strengths and weaknesses of the design and operation of a nuclear power plant.

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Term	Acronym / Abbreviation	Description Definition
Qualification Program		The overall cumulative process of specifying, conducting, and documenting the results of those activities required to qualify active mechanical equipment to perform its function in accordance with the Qualification Specification [1].
Qualification Report		Documentation of tests, analyses, operating experience, or any combination of these performed in accordance with this Standard or the Qualification Specification that demonstrates functionality of the active mechanical equipment [1].
Qualification Specification		The specification or portion of the Design Specification that describes the qualification requirements to be met in the qualification of the active mechanical equipment [1].
Rated load		The design load capacity for the restraint based on the use of Service Level A [1].
Reactor building	RXB	
Reactor enclosure system	RES	
Reactor head	RH	
Reactor support structures	RSS	
Reactor vessel	RV	
Regulatory guide	RG	
Reliability and integrity management	RIM	Those aspects of the plant design process that provide an appropriate level of SSC reliability and a continuing assurance that such reliability will be maintained over the life of the plant. RIM aspects include design features important to reliability performance, such as design margins; material selection; testing and monitoring; provisions for maintenance, repair, and replacement; leak testing; and NDE.
Reliability target		A performance goal established for the probability that an SSC will complete its specified function to achieve plant-level risk and reliability goals.
RIM expert panel	RIMEP	
RIPB Seismic Target Performance Goal		Seismic performance goal denoting a mean annual frequency of unacceptable seismic performance, commensurate with the risk objectives of the plant
Risk informed performance-based	RIPB	A licensing Strategy that infers implementation of NEI 18-04 [2]
Rotatable plug assembly	RPA	
Safe Shutdown Earthquake	SSE	Safe shutdown earthquake ground motion is the vibratory ground motion for which certain structures, systems, and components must be designed to remain functional during and/or after a seismic event to assure safe shutdown of the plant.
Safety related	SR	

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Term	Acronym / Abbreviation	Description Definition
Seismic isolation system	SIS	
Seismic PRA	SPRA	Probabilistic Risk Assessment that is specific to seismic hazards.
Service Conditions		Postulated conditions specified for environmental, dynamic/static/pressure loadings, material degradation, etc., for normal operation, abnormal operation, and design-basis events [1].
Service Level		Design, Service (A through D), Test Limits and expected performance for each Service Level are provided in ASME.BPVC.III Subsection NCA-2142.4 [3].
Spring Rate		The linear approximation of the relationship of the load displacement characteristics of the restraint [1].
Standard Review Plan	SRP	
Structures, systems and components	SSC	
Umbilicals or umbilical lines		Umbilical lines are nonstructural components and systems (mainly distribution systems) that cross the isolation interface and must sustain the large isolator displacements (or deformations) associated with design basis and extended design basis ground motions. Examples of umbilical lines could include system piping and electrical and I&C cables [6].
Uncertainty (as used in MANDE)		A quantification representing the variability associated with monitoring and non-destructive examination data and includes many technique and application specific parameters such as the minimum detection capability, sizing accuracy, resolution tolerance, repeatability, consistency, etc.
Uncertainty (as used in PRA)		A representation of the confidence in the state of knowledge about the parameter values and models used in constructing the PRA.
Uniform Hazard Response Spectra	UHRS	A set of site specific hazard response spectra developed through a Probabilistic Seismic Hazard Analysis (PSHA). UHRS are developed for multiple not-to-exceed frequencies.

5 BACKGROUND

5.1 Natrium Plant Description

The Natrium plant utilizes a pool-type, metal-fuel sodium fast reactor paired with a molten salt energy island. Using the pool-type molten sodium cooled reactor offers several distinct advantages when compared with traditional light water reactor designs. Molten sodium provides a simplified response to abnormal events due to its large thermal inertia inherent to the large volume of liquid sodium in the reactor. Additional benefits of molten sodium include high thermal efficiency due to its high thermal conductivity and low viscosity, and chemical compatibility with stainless steels, reducing the risk of corrosion or other adverse reactions. Furthermore, sodium remains liquid over the full operating temperature range at near atmospheric pressure, eliminating the need for high pressure primary coolant systems.

The paramount mission of the Natrium reactor is to deliver safe, carbon-free power to society. Its simplified inherently safe design enables deployment across a wide range of sites. The Natrium plant comprises the nuclear island and the energy island. The energy island includes thermal energy storage and a power conversion unit, while the nuclear island includes the reactor and supporting safety-significant structure, systems and components (SSC).

The Reactor Building (RXB) is at the center of the nuclear island located between the Fuel Handling Building and the Reactor Auxiliary Building as shown in Figure 5-1. The RXB houses safety-significant systems including the Reactor Enclosure Systems (RES) which houses the reactor core. There are two main levels in the RXB: the refueling access area floor located at-grade level in the RXB steel-framed superstructure, and the operating deck, also known as the Head Access Area (HAA) located below grade in the reinforced concrete and steel RXB substructure. The HAA provides maintenance access to the reactor head and its associated piping and equipment. The reactor is located within, and supported by, the embedded RXB substructure that provides protection from external hazards. The reactor support design incorporates seismic isolation of the reactor from the RXB substructure to provide enhanced protection against seismic events. Heat generated by the reactor core is transferred through the intermediate heat exchanger to the intermediate sodium loops through piping umbilicals from the Reactor Auxiliary Building (depicted in Figure 5-1).

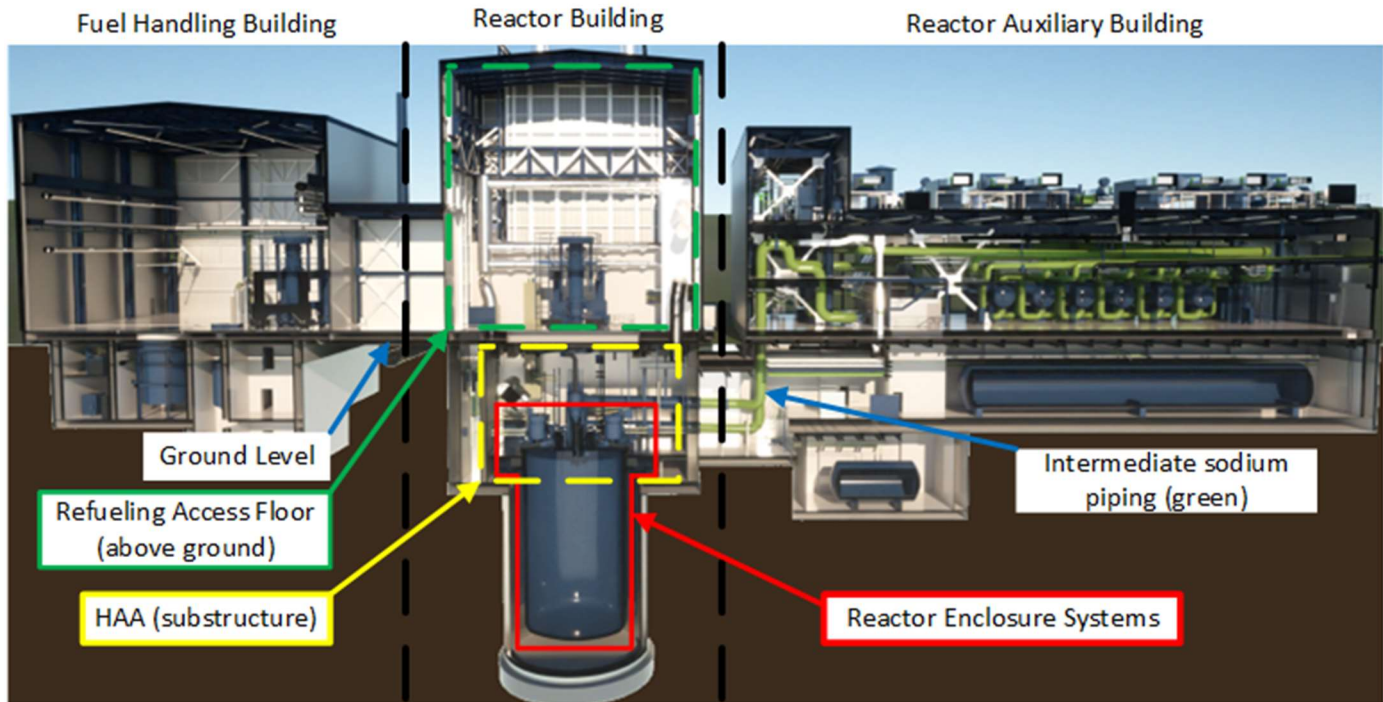


Figure 5-1: Cross Section View of Nuclear Island Buildings. From left to right: Fuel Handling Building (FHB), the Reactor Building (RXB) and the Reactor Auxiliary Building (RAB).

5.2 Industry Technical Reports

Despite the lack of implementation of seismic isolation systems (SIS) for nuclear power plants (NPP) in the United States, advanced reactor vendors have an interest in exploring the use of SIS. One such advanced reactor design utilizing SIS appears in General Electric's preapplication for a liquid metal reactor, PRISM, in the 1980s [7] which utilized composite steel-rubber seismic isolation devices. The US Nuclear Regulatory Commission (NRC) initiated several research programs in the 2000s to examine potential regulatory paths and performance of selected SIS through experimental studies. There are three technical reports prepared for the NRC that discuss potential regulatory guidance and technical considerations for seismic-isolated NPPs. The three reports are NUREG/CR-7253 [6], "Technical Considerations for Seismic Isolation of Nuclear Facilities," issued February 2019; NUREG/CR-7254 [8], "Seismic Isolation of Nuclear Power Plants using Sliding Bearings," issued May 2019; and NUREG/CR-7255 [9], "Seismic Isolation of Nuclear Power Plants using Elastomeric Bearings," issued February 2019.

The objective of NUREG/CR-7253 is to develop and summarize 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, performance-based design philosophy for SIS that is intended to be consistent with the NRC's then-current objectives and criteria approaches. This report focuses on base-isolation of NPPs using two-dimensional (horizontal) bearing type isolation systems. NUREG/CR-7253 does not address the use of three-dimensional SIS for applications such as equipment isolation. NUREG/CR-7253 assumes the isolation of surface or near-surface-mounted, safety-related (SR) structures such as large light water

reactor buildings. Although the report focuses on surface-mounted SIS consisting of isolation devices which are active only in the horizontal direction, the authors argue the principles discussed should apply more broadly to additional SIS technologies and mounting configurations.

The objective of NUREG/CR-7254 is to develop and codify a model to characterize the dynamic response of a particular type of horizontal SIS: Concave Friction Pendulum™ (FP) bearing. The report presents the mechanical design of FP bearings and describes the relationship between force and displacement, velocity, and friction coefficient, and the hysteretic dependency of the dynamic response to earthquake shaking. The mathematical model presented in Section 3 of the technical report is implemented in an open-source finite element computer code through use of a specific element library, and numerical results from the model are validated with published experiments. Additionally, the report performs a risk-based calculation to compute design factors for seismically isolated NPPs and understand the impact of modeling decisions and loading conditions.

The objective of NUREG/CR-7255 is to investigate existing applications of SIS in nuclear structures and focuses on elastomeric seismic isolation technology including Low Damping Rubber (LDR) and Lead-Rubber (LR) bearings. The report recommends an appropriate mathematical representation for elastomeric bearing for extreme earthquake shaking to account for non-linear effects such as softening due to cavitation. Models to simulate these characteristics are implemented in open-source and commercially available finite elements software. The models are then exercised using seismic motions scaled to a uniform hazard response spectrum with a return period of 10,000 years and conclusions are drawn regarding the efficacy of the technology for design basis earthquake and beyond design basis earthquake.

The current publicly available technical reports issued by the NRC primarily focus on SIS that are effective only in the horizontal direction and applied to building structures (with a similar configuration to the one shown in Figure 5-2). However, the considerations, principles, and recommendations provided by these documents can be extended to other technologies and applications, including three-dimensional SIS arrangements designed to isolate equipment rather than structures, and risk-informed licensing frameworks to achieve the desired seismic performance objectives. These additional seismic isolation technologies and applications merit additional considerations and requirements beyond the ones noted in the current NRC reports and are outlined in this report.

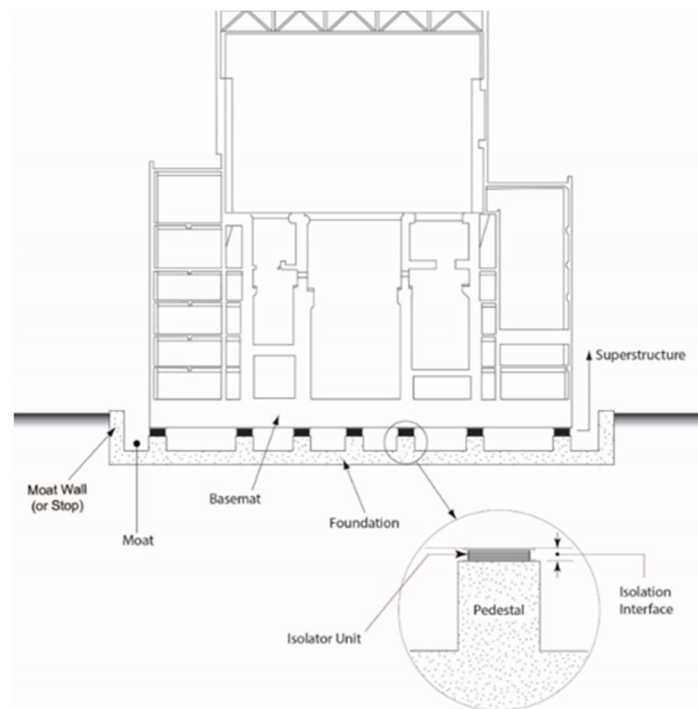


Figure 5-2: Elements of a seismically isolated nuclear plant structure [6]

5.3 Regulatory Precedence

The US NRC has issued its safety evaluation report (SER) of an advanced test reactor for a construction permit [10]. In its evaluation the staff noted in Section 3.5.3.2 of [10]:

“Based on its review of the PSAR, the staff finds that Kairos has provided an adequate level of detail on the seismic isolation system for the preliminary design and for issuance of a CP because, although details of the isolation system have not been specified, the design methodology aligns with a consensus code (ASCE 43-19) and Kairos has clearly identified information that will be provided in the OL application.”

The construction permit recommended by the SER to be approved by the US NRC endorses the application of seismic isolation in nuclear facilities which can limit the seismic demand on safety related SSCs.

5.4 Basis for Performance Criteria Adaption

The underlying seismic performance criteria recommended in NUREG/CR-7253 rely on discrete design requirements for design basis and beyond design basis earthquakes, but without explicit evaluation of seismic risk quantified across the whole range of seismic hazard and the associated potential for cliff-edge effects. Consistent with the licensing modernization project approach described in NEI 18-04 [2], and endorsed by RG 1.233 [11], risk insights from functional performance across the complete range of seismic hazard can affect cumulative risk objectives such as quantitative health objectives (QHO). Therefore, although the recommended seismic performance objectives for seismic isolation presented in NUREG/CR-7253 are useful guiding principles, the corresponding design framework recommended

is not fully compatible with the risk-informed performance based (RIPB) approach endorsed by RG 1.233 [11].

Furthermore, three-dimensional equipment isolation is distinctly different from two-dimensional full scale building isolation with the following considerations:

- Target isolation frequency for equipment is typically larger (in the range of 1-4 Hz) than those for building isolation (in the range of 0.5-2 Hz). Displacement of the isolated equipment relative to non-isolated structures may be more limited than in building isolation applications.
- Equipment isolation footprint is considerably smaller than that of building isolation, providing smaller scale load distribution control and reduced uncertainties (weight, stiffness, load distribution, stiffness, etc.).
- The total mass of the isolated equipment is significantly reduced when compared with full building isolation, simplifying the analysis and qualification.
- Equipment isolation benefits from three-dimensional isolation by tuning the horizontal and vertical isolation frequencies to balance reduction in seismic demand in all three directions and to minimize rocking of the equipment.
- Equipment isolation is located inside the building providing protection from external environmental conditions to a much greater extent thereby reducing degradation mechanisms. On the other hand, proximity to the reactor may increase the significance of temperature and radiation exposure.
- Access to equipment isolation requires different considerations, including entering potential radiation zones and providing direct access to inspections and maintenance in confined spaces.

Given the limited available regulatory guidance and the considerations listed above, development of a design and qualification methodology for equipment isolation using three-dimensional seismic isolation technology is warranted. Such methodology can adapt seismic performance objectives similar (or equivalent) to existing published guidance as presented in NUREG/CR-7253 for alignment and consistency with the RIPB approach endorsed by RG 1.233 [11].

6 NATRIUM REACTOR SEISMIC ISOLATION SYSTEM

The primary system to be supported by the SIS is the RES, and the preliminary arrangement of the RES is shown in Figure 6-1 (equipment supported by the RES and umbilicals are not shown). The RES includes the reactor vessel and head, which encompasses the reactor core, reactor internal structures, primary sodium coolant, and essential equipment required for coolant circulation and reactor heat rejection. The RES incorporates a guard vessel surrounding the reactor vessel, offering defense-in-depth leak mitigation in the unlikely event of a primary sodium leak from the RV. The RES is supported by the reactor support structure (RSS), which includes the modular isolated reactor support structure (MIRSS), reactor support blocks, and SIS, and provides the load path from the reactor vessel head to the reactor building substructure basemat. The plant equipment that is isolated from the RXB by the SIS includes:

- RES and RES Internals:
 - Reactor Enclosure System, including the Reactor Vessel and Head, Rotatable Plug Assembly, Reactor Internals Structures, and the Reactor Support Structure.
 - Reactor Core System, including the Fuel, Control, Shield and Reflector Assemblies.
- Equipment attached or supported by the RES:
 - Control Rod Drive System, including the Control Rod Drive Mechanisms and drivelines.
 - Primary Heat Transport System, including the Intermediate Heat Exchangers and Primary Sodium Pumps.
 - Reactor Air Cooling System Collector Cylinder.
 - Sodium Cover Gas System components mounted on the Reactor Head.
 - Sodium Processing System, including the Main Heat Exchanger and Pump.
 - In-Vessel Fuel Handling System including the Fuel Transfer Lift and the In-Vessel Transfer Machine.
- RES Umbilicals:
 - Intermediate Heat Transport System piping connected to the intermediate heat exchangers.
 - Sodium Cover Gas System and Sodium Processing System piping.
 - Reactor Instrumentation System instruments and cabling.

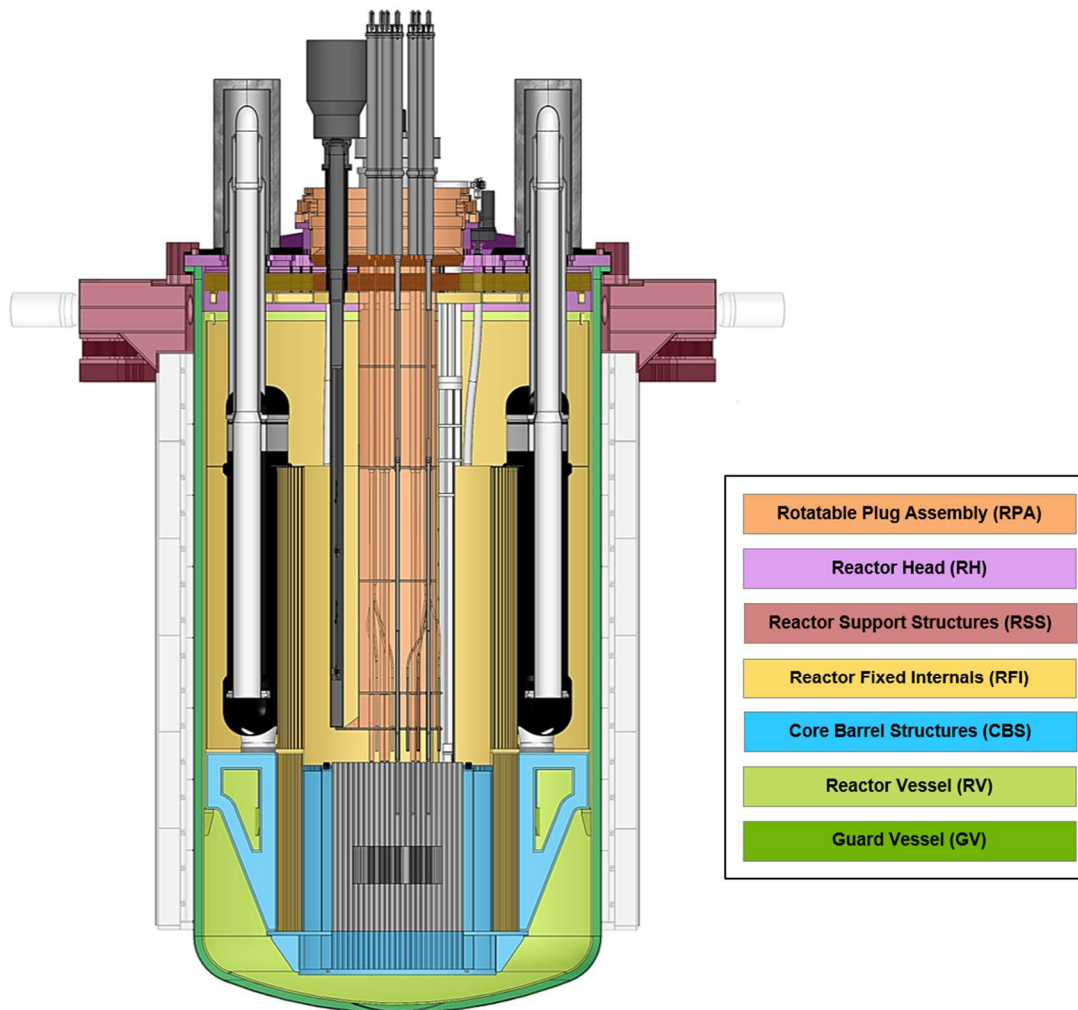


Figure 6-1: Reactor Enclosure System

The SIS is located at the interface between the RSS and the RXB and is attached to the HAA reinforced-concrete basemat and the MIRSS as shown in Figure 6-2. The MIRSS is a plate-girder steel structure which supports the RES on its inner diameter ledge through the reactor support blocks. The MIRSS, along with the reactor support blocks, constrain the reactor head such that a stiff load-path from the reactor head to the SIS is formed, while accommodating the relative thermal growth between the MIRSS and the basemat. The MIRSS also supports the collector cylinder assembly, which is suspended on the underside of the MIRSS around the reactor to support the reactor air cooling function.

The RSS incorporates the SIS, which isolates the reactor from the supporting RXB basemat using three-dimensional SIS technology. The SIS includes multiple isolation spring units (ISU) and isolation damper units (IDU) alternately located in a circular pattern within the RSS as shown in Figure 6-2. The ISUs are constructed of coiled helical wire springs in parallel between a top and bottom mounting plate. The dampers consist of the damper housing, which is a non-pressurized fluid container filled with viscous damper fluid and a piston immersed in the fluid [12]. The damper housing and the piston are attached to opposite end plates of the damper. As a result of relative movement of the piston within the housing, forces resulting from the motion of the viscous fluid provide effective load transfer and motion damping between the supporting and supported SSC.

The ISUs and IDUs require to be sized and calibrated for adequate attenuation of seismic loads and support of the RES during normal and off-normal conditions. The ISUs serve to provide sufficient separation between the frequencies of motions transmitted from the RXB and the fundamental frequency of reactor internal equipment. The IDUs provide damping forces during seismic motions which limit displacement and the transmitted forces to critical equipment. The IDUs are unloaded when the reactor is at rest and provide negligible resistance to quasi-static motions such as thermal expansion. The ISUs and IDUs are coupled by the stiff MIRSS and HAA basemat to ensure even load distribution within the SIS and limit the seismic demands exerted on the safety related reactor from seismic motions.

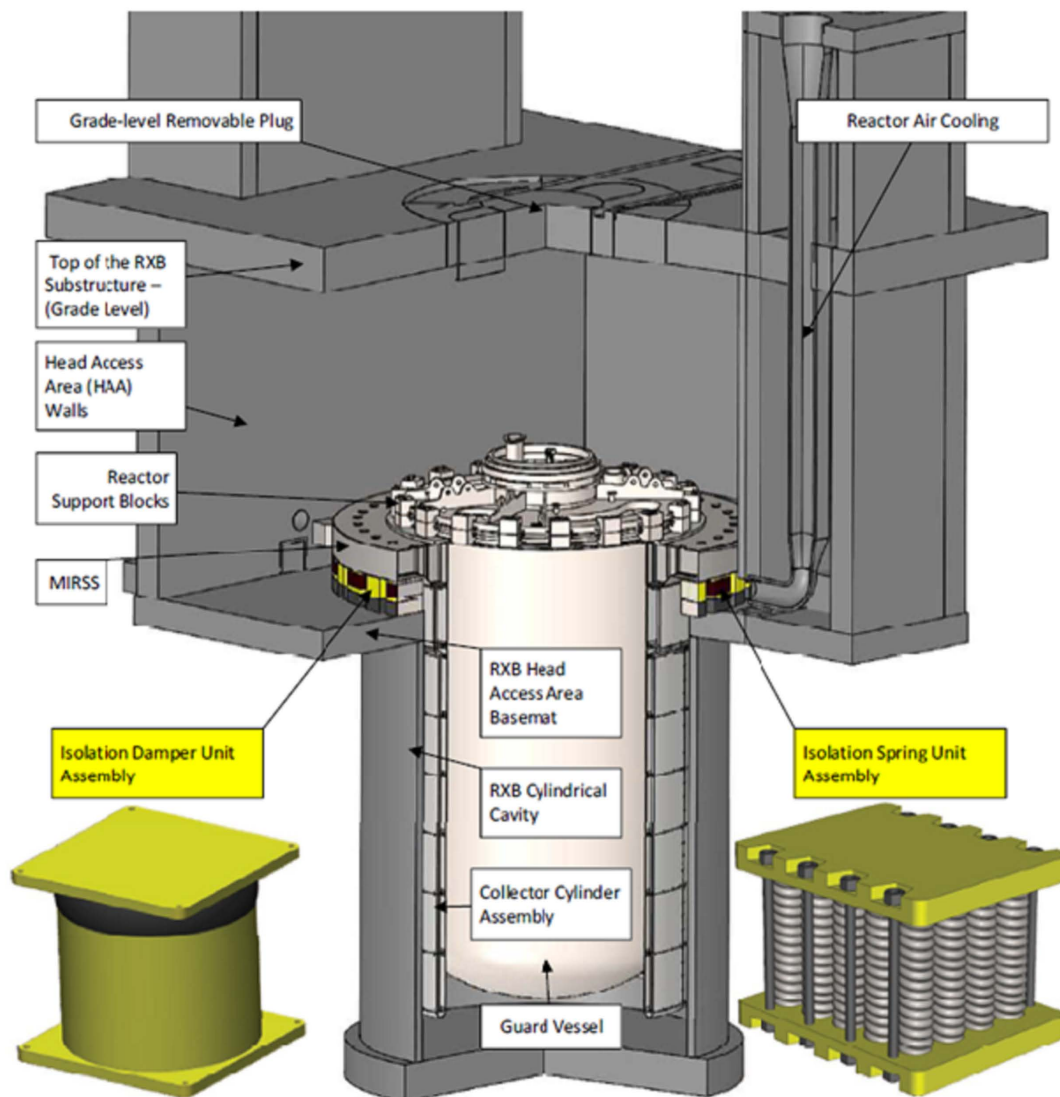


Figure 6-2: Conceptual RES SIS arrangement and interface with the RXB.

6.1 Sodium Reactor Seismic Design Process and Applicability of this Report

The SIS design in accordance with the requirements of this Topical Report can rely on either specific or generic qualification process. When the specific qualification process is pursued, site-specific

motions and a particular design of RXB, SIS and supported subsystems are considered. Seismic qualification in this case is limited to the site and particular RXB, SIS and supported subsystems design, and must be repeated for other sites or if significant changes are implemented to the RXB, SIS or supported subsystems.

The approach for the generic qualification is as follows:

1. A generic broad-band high amplitude spectra is developed to envelop the expected shaking intensities at the interface between the supporting structure and the SIS at a wide range of potential sites (including Kemmerer Unit 1).
2. Seismic analyses are performed to establish SIS performance and demand consistent with generic conservative shaking intensities. Constitutive models of SIS properties are established based on industrial experience with 3D seismic isolation properties and used as a starting point for seismic demand generation. RXB, SIS and SIS supported subsystems are sized to meet this demand.
3. Qualification tests are performed to demonstrate the SIS performance meets the requirements of this Topical Report when subjected to the demand generated in the previous step. SIS constitutive models from the previous step are either confirmed or calibrated using results from qualification tests. If calibration of the SIS properties is needed, the demand and associated designs are reconciled.
4. Seismic analyses are performed as a confirmatory step using the site-specific motion profile. If the demand resulting from these motions is shown to be bounded by the demand which was generated using the generic spectra, and all requirements of this Topical Report are met, the SIS is considered qualified. If the demand derived from the site-specific motions exceeds the demand that was generated in step 2, new enveloping motions must be generated, and the qualification process must be repeated.

7 REACTOR SEISMIC ISOLATION SYSTEM DESIGN AND QUALIFICATION METHODOLOGY

This section outlines the reactor SIS design and qualification methodology including the technical basis, and applicable regulatory guidance. The following topical areas were considered in the overall process for developing the reactor SIS design and qualification methodology for application to three-dimensional equipment isolation utilizing IDUs and ISUs:

- Risk-informed performance based seismic classification and design of the SIS.
- Evaluation of design-specific applicability of industry standards to the SIS including identification of the codes and standards based on operating experience and prior precedence in nuclear applications.
- Evaluation of design-specific applicability of industry technical information for the SIS consistent with the NEI 18-04 [2], RIPB approach. Adaptation of seismic performance objectives similar (or equivalent) to existing published technical information, such as is in NUREG/CR-7253 [6].
- Requirements allocation to establish performance criteria for the SIS. Requirements may be categorized as functional, performance, and interface requirements or design constraints. Requirements are elicited from expected SIS safety classification, technical considerations

applicable to reactor seismic isolation based on review of industry technical reports, and applicable codes and standards.

- Reactor SIS analysis to derive the critical SIS parameters that form the basis for qualification and verification of the requirements and performance criteria.
- Design and construction requirements pertaining to ASME certificate holder responsibilities.
- Qualification program description with specific applicability to both ISUs and IDUs that includes augmenting the requirements of the construction code.
- Life-time management description for assuring the reliability and integrity of the SIS over the life of the plant.

The discussion provided for the topical areas in the following sections elaborate on the context, background, and rationale for the presented methodology and will be incorporated as part of the SIS design and qualification basis documents when approved.

7.1 Risk-Informed Performance Based Seismic Design and Classification Process

Natrium is using a RIPB approach to seismic design and qualification that is consistent with NEI 18-04 [2]. NEI 18-04 establishes a RIPB decision making process that incorporates principles of frequency of event occurrences versus consequences of failure and measurable performance objectives.

Seismic design requirements are identified through an iterative process that considers SSC design capability and seismic risk, informed by a seismic probabilistic risk assessment (SPRA). The iterative process establishes the required seismic performance criteria based on SSC seismic risk significance, and seismic special treatments inform SSC design and qualification requirements such that there is reasonable assurance that required seismic performance is achieved. Seismic performance criteria and special treatments are applied commensurate with the SSC safety-significance and contribution to seismic risk. The SIS is classified safety-related and has been determined to be a risk significant contributor to overall plant seismic risk, and a rigorous approach to the identification of seismic performance requirements and the application of seismic special treatment has been developed, as described herein.

The RIPB approach to seismic design and qualification supplements existing and applicable regulations to nuclear power plants.

7.1.1 Seismic Design Basis Hazard Level

The Design Basis Hazard Level (DBHL) for Natrium is established as the Safe Shutdown Earthquake (SSE) based on guidance provided in RG 1.208 [5]. A probabilistic seismic hazard analysis (PSHA) is performed as part of a Senior Seismic Hazard Analysis Committee (SSHAC) Level 3 study. The PSHA, in combination with a probabilistic site response analysis, is used to develop site-specific Uniform Hazard Response Spectra (UHRS) within the site profiles needed for performing seismic analysis. The hazard consistent, site-specific ground motion response spectra (GMRS) is developed from the UHRS at or near the ground surface or top of competent material using guidance from RG 1.208 [5] and NUREG/CR-6728 [13]. The GMRS is used to develop the SSE and forms the basis for development of foundation input response spectra using soil-structure interaction analysis.

The seismic DBHL is initially used in the Natrium CPA to inform Licensing Basis Event (LBE) selection and the safety classification process under NEI 18-04 [2]. In addition, the seismic DBHL is used to satisfy the requirements for the Seismic Design Basis Accident (DBA) LBE, which evaluates the design for SR SSCs to withstand the effects of the seismic DBHL without loss of capability to perform their required safety functions. In addition to evaluating DBAs, full implementation of NEI 18-04 [2] requires the evaluation of event sequences for selection of LBEs that include Anticipated Operational Occurrences (AOOs), Design Basis Events (DBEs), and Beyond Design Basis Events (BDBEs) to the full range of seismic events to confirm the adequacy of safety classifications and special treatments.

The SSE bounds terminology for the GMRS and DBHL and will be used for establishing the reference DBHL for SIS qualification requirements.

7.1.2 Seismic Classifications and Seismic Special Treatments

Graded seismic classifications are used to assign seismic special treatments and associated design requirements for SSCs and safety functions, consistent with the safety classifications developed under NEI 18-04 [2]. Seismic Classifications, or seismic special treatment categories, are assigned a set of seismic special treatments that inform the design, qualification, and quality requirements for project life cycle phases and define seismic design requirements via a graded application of codes and standards. The resulting seismic performance of SSCs can be verified through feedback between SSC design and the seismic PRA via the fragilities associated with the seismic special treatment categories to evaluate the seismic risk significance of SSCs against a RIPB seismic target performance goal.

The adequacy of the assigned seismic classifications and associated special treatments, are evaluated through an iterative process between design and SPRA. The overall process is outlined as follows:

- Initial safety classifications assigned to SSCs consistent with the NEI 18-04 [2] safety classification process: safety related (SR), non-safety related with special treatment (NSRST), non-safety related with no special treatment (NST).
- Preliminary seismic design for SSCs is performed based on assigned seismic criteria.
- Update SPRA using conservative SSC fragilities developed from assigned seismic criteria.
- Feedback from SPRA results used to evaluate SSC seismic risk significance and update SSC fragilities to meet NEI 18-04 [2] risk targets.
- Update SSC seismic design and fragilities, and iterate based on SPRA feedback as needed.

Feedback from SPRA is used to evaluate whether seismic classifications for SSCs and/or safety functions warrant a change based on seismic risk significance and will identify seismic event sequences that require SSC specific or refined fragilities beyond those established by the seismic classifications. These fragilities may be used to inform additional SSC specific seismic special treatments to meet Natrium's risk objectives and associated SSC seismic performance criteria to supplement the design and qualification requirements for the SIS. The overall RIPB SIS seismic design and seismic classification process is illustrated in Figure 7-1.

The reactor SIS ISUs and IDUs are assigned a SR designation under the NEI 18-04 [2] safety classification process and has a SR seismic risk significant special treatment category designation, consistent with an SCS1 seismic classification. The seismic special treatments associated with the

SCS1 classification specify that, at minimum, SSCs are designed to withstand the effects of the SSE and remain functional and the pertinent quality assurance requirements of Appendix B to 10 CFR Part 50 [14] will be applied to all activities affecting the safety-related functions of the SIS, which is reflected in the selection of applicable Codes and Standards.

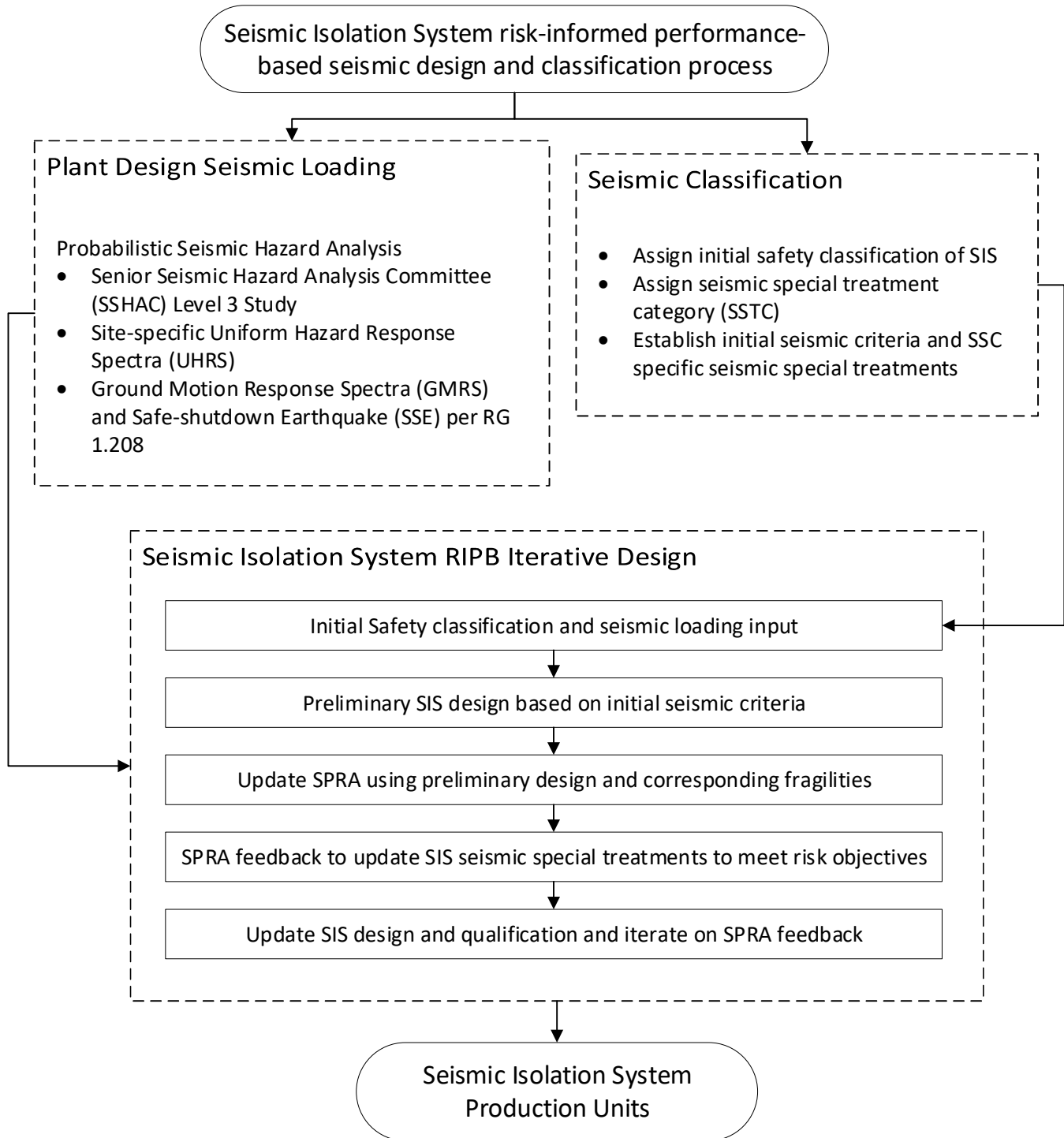


Figure 7-1: Seismic Isolation System risk informed performance-based design process.

7.2 Reactor Seismic Isolation System Industry Standards

ASME Boiler and Pressure Vessel Code, Section III

The design and construction of high-temperature reactor coolant boundary components, including the reactor vessel and head, are governed by ASME BPVC Section III, Division 5 (ASME.BPVC.III.5) "High Temperature Reactors" [15], as endorsed by RG 1.87 [16]. Per RG 1.87 Table A-1, the RV and RH are ASME.BPVC.III.5 Class A components, and Subsection HB Class A Metallic Pressure Boundary Components and Subpart B Elevated Temperature Service (HBB) apply. In accordance with the requirements of ASME.BPVC.III.5 [15], supports of high temperature reactor systems are designed and constructed to the requirements of ASME.BPVC.III.5, Subsection HF Class A and Class B Metallic Supports. Preliminary analyses indicate that the RSS temperatures do not exceed the permitted values in ASME.BPVC.III.5 HAA-1130-1 and therefore, Subpart A Low Temperature Service applies. Furthermore, per ASME.BPVC.III.5 HFA-1110(b), the rules of Subsection HF, Subpart A are contained in ASME.BPVC.III.1, Subsection NF [17].

In accordance with ASME.BPVC.III.5 HFA-1110(g), the rules of ASME.BPVC.III.1 Subsection NF do not apply to spring elements and damper unit hydraulic fluid, except for the following requirements:

1. Material shall tolerate the environmental conditions.
2. The exempt item shall be designed to the same loading as other requirements for non-exempt parts.
3. The design specification and design report shall indicate the exempt items.
4. Materials, fabrication, and installation shall comply with the design output documents.
5. Spring coils shall be inspected to ASME.BPVC.III.1 NF-2520.
6. Compression spring (soft compression stops) end plates shall comply with ASME.BPVC.III.1 NF-3000, NF-4000, NF-5000, and NF-8000.
7. Compression dynamic stops shall comply with ASME.BPVC.III.1 NF-3000, NF-4000, NF-5000, and NF-8000.

NUREG-2245 [18] provides a technical review of ASME.BPVC.III.5. NUREG-2245 Section 3.17 [18] details the review of Subsection HF Class A and Class B Metallic Supports with the conclusion that the NRC staff finds the ASME BPVC acceptable for designing Class A component supports such as the supports for the RV.

Jurisdictional boundaries between component supports and the building structure are governed by ASME.BPVC.III.1 NF-1132. Figure NF-1132-1 includes typical examples of jurisdictional boundaries. Figure NF-1132-1(e) shows a typical arrangement in which a damper element is included with the component support (also shown in Figure 7-2). The damper and the supporting steel structure attached to the building structure is under the jurisdiction of ASME.BPVC.III.1 Subsection NF. There are three types of support categories in accordance with NF-1200. Standard supports are those identified in NF-1214 that include constant and variable type springs, and dampers. Typical examples of standard supports are provided in Figure NF-1214-1 (see Figure 7-2). The SIS components are therefore considered standard supports and governed under the jurisdiction of ASME.BPVC.III.1, Subsection NF. Per NF-3411.1, standard supports can be used as component supports, such as the SIS supports for

the RV. As such, the ASME BPVC Section III provides a complete set of rules for construction (including design, materials, fabrication, testing, examination, and installation) commensurate with ASME NQA-1 [19] and NCA [3] (N-type certification). The ASME BPVC is flexible to accommodate a range of user-specified seismic performance criteria.

The use of ASME.BPVC.III.1, Subsection NF is prevalent in NPPs. In accordance with NUREG-0800 Standard Review Plan (SRP) 3.9.1 [20] the operating fleet reactor vessel supports were designed and constructed to one of the Editions of ASME.BPVC.III.1, Subsection NF. Reactor vessel supports in recent license approvals for the Westinghouse AP1000 [21], GEH ESBWR [22], and NuScale US600 [23] also used one of the Editions of ASME.BPVC.III.1, Subsection NF for reactor supports. The precedence cited did not employ seismic isolation systems.

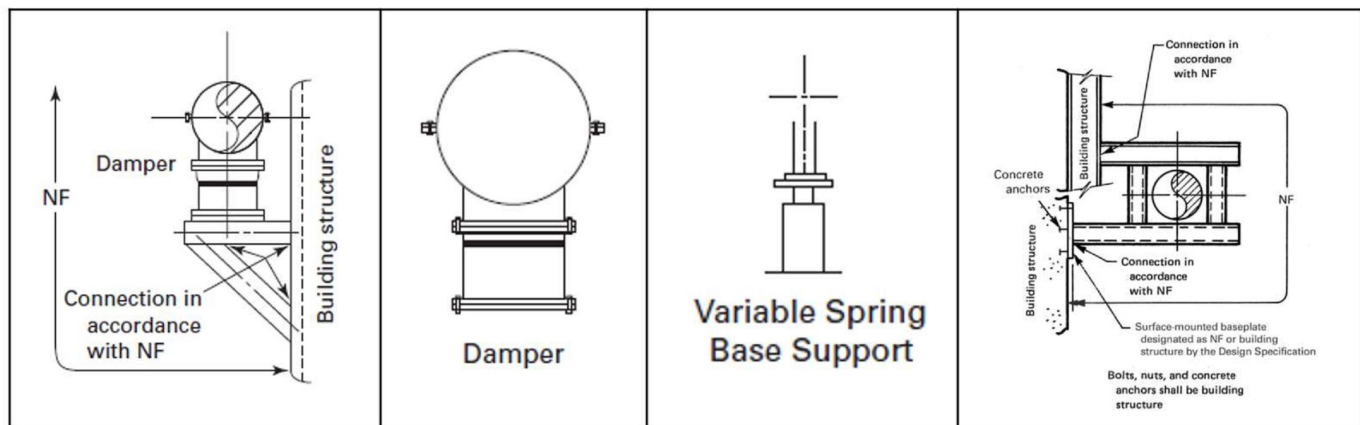


Figure 7-2: ASME jurisdictional boundary example (left); spring standard support (second from left); damper standard support (second from right); ASME jurisdictional boundary with concrete anchors (on the right)

SIS anchorage jurisdictional boundary follows ASME.BPVC.III.1, Subsection NF Figure NF-1132-1.f and shown in Figure 7-2. on the right. Anchorage between SIS components and building concrete is considered Building Structures and designed in accordance with ACI 349 Appendix D – Anchoring to Concrete [24]. All bolting between SIS components and interfacing steel structures is designed to meet the rules of ASME.BPVC.III.1, Subsection NF 3324.6 rules for Friction-Type Joints.

ASME QME-1

The purpose of ASME QME-1, Qualification of Active Mechanical Equipment Used in Nuclear Facilities [1] is to provide requirements to qualify active mechanical equipment based on critical characteristics to meet functional requirements for licensing basis events. The reactor SIS falls under the qualification program of ASME QME-1. Section QDR of ASME QME-1 provides rules for qualification of dynamic restraints and section QR discusses the associated general requirements. The boundaries of jurisdiction of ASME QME-1 align with those defined in ASME.BPVC.III.1, Subsection NF and governed by QDR-1100. Qualification principles based on functional requirements pertaining to the spring rate and damping resistance (defined in QDR-3000) of dynamic restraints are in QDR-4000 (QDR-4400 Viscoelastic Dampers). In accordance with QDR-5000, the Owner shall provide a Qualification Specification which is reconciled with the Design Specification per ASME.BPVC.III.1, Subsection NF. The qualification program, governed by QDR-6000 and QDR-7000 (for documentation), generally includes the following elements:

- Approach to qualification (QDR-6210).
- Testing plan (QDR-6220):
 - Installation and orientation
 - Test and monitoring equipment
 - Test sequence
 - Functional parameter testing for springs
 - Functional parameter testing for viscoelastic dampers
 - Aging and service condition simulation
 - Limits or failure definition
 - Post-test examination and analysis
- Parent or candidate qualification (similitude and analysis, QDR-6200 and QDR-6300).
- Documentation requirements (QDR-7000):
 - Qualification plan (QDR-7200)
 - Qualification and application reports (QDR-7300)
- Additional details on the content of the Qualification Specification are provided in Mandatory Appendix QDR-I.

Therefore, the use of ASME QME-1 augmenting ASME.BPVC.III provides the basis for complete qualification of the SIS prior to placing it in service. The qualification establishes the baseline for inservice activities including monitoring, inspection, testing, maintenance, and surveillance.

ASME BPVC, Section XI

For completeness, it is noted that the Reliability and Integrity Management (RIM) program, outlined in the ASME BPVC, Section XI, Division 2 (ASME.BPVC.XI.2) [4], applies to safety related supports. The 2019 Edition of this code was endorsed by the U.S. NRC in RG 1.246 [25]. The reactor and its support including the SIS is included under the RIM program which addresses inservice inspections, monitoring, and surveillance for the entire operating life of the plant.

The reactor support SIS design and qualification codes and standards applicability is summarized in Figure 7-3.

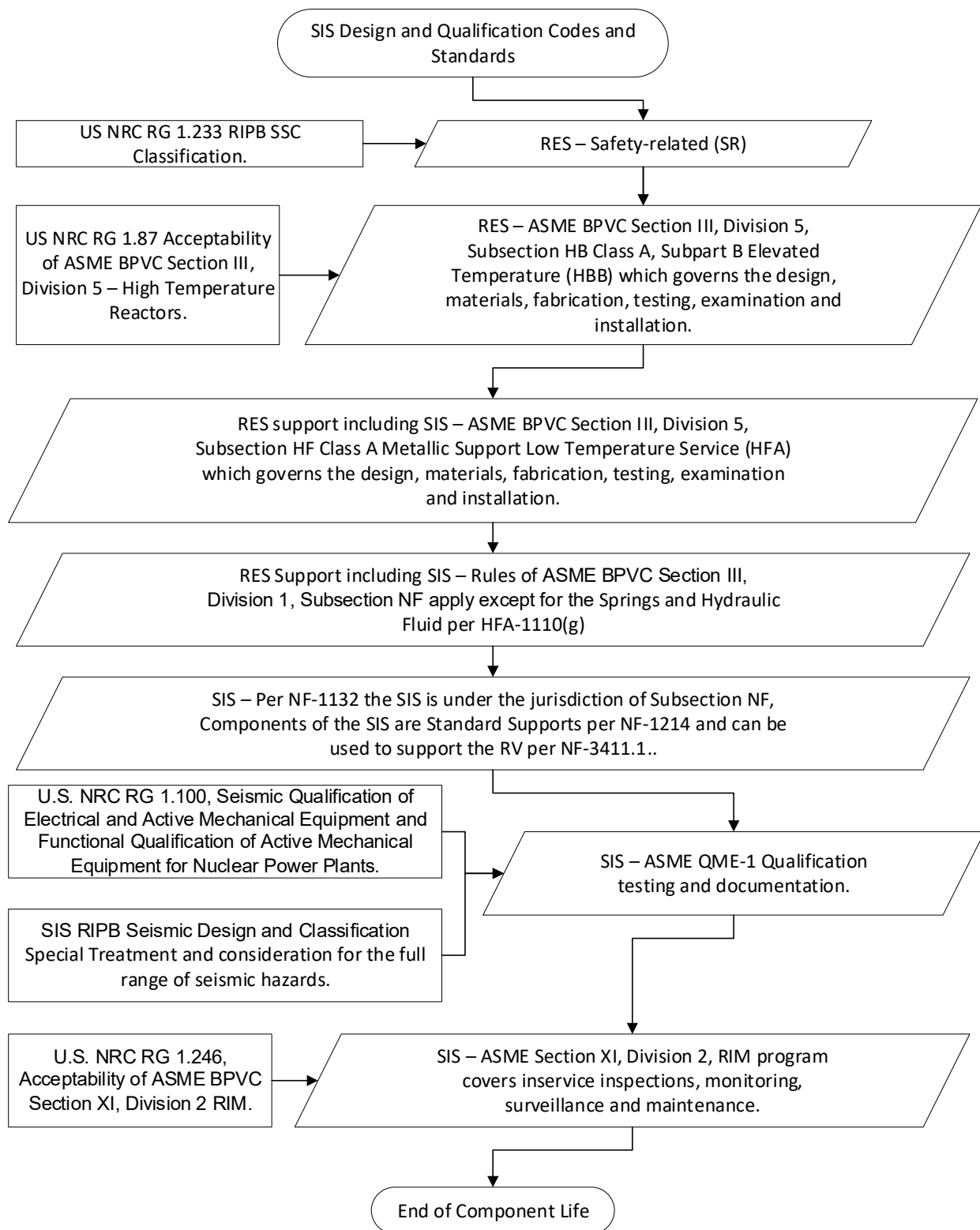


Figure 7-3: Reactor Seismic Isolation System Design and Qualification Applicable Codes and Standards

7.3 Commentary on Seismic Isolation NRC Reports

The information provided in NUREG/CR-7254 [8] and -7255 [9] was reviewed and determined not to apply to the Sodium reactor SIS design and qualification methodology. Review of NUREG/CR-7253 [6] determined that the guidance warranted a detailed assessment of applicability of technical considerations.

The stated objective of NUREG/CR-7253 is to develop and summarize 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 states that it presents a risk-informed, performance-based design philosophy for seismic isolation that is consistent with the NRC's then-current objectives and criteria approaches.

Based on a review of NUREG/CR-7253, the underlying performance assumptions rely on discrete design requirements for design basis and beyond design basis earthquakes without explicit evaluation of seismic risk resulting from the full range of external hazards, and the associated potential for cliff-edge effects. NUREG/CR-7253 is not consistent with the licensing modernization approach described in NEI 18-04 [2], which relies on evaluation of risk insights from the full range of external hazards to meet QHOs. Furthermore, NUREG/CR-7253 focuses on base-isolation of NPPs using horizontal bearing type isolation systems. As noted in Section 5.4, three-dimensional equipment isolation is distinctly different from two-dimensional full scale building isolation.

However, the technical considerations presented in NUREG/CR-7253 were reviewed to identify relevant inputs, and the results of the review are provided in the form of a commentary on the applicability to the Sodium three-dimensional reactor SIS design and qualification methodology in Table 7-1.

Table 7-1 identifies each technical area applicability in three categories:

- Applicable – the technical area or requirement is applicable and corresponding requirement(s) is adapted for which compliance will be demonstrated.
- Not Applicable – the technical area or requirement is not applicable to the three-dimensional reactor SIS.
- Meet Intent – the technical area or requirement is not directly applicable however the underlying intent or performance target is adapted in an alternate requirement which meets the intent.

Those requirements that are deemed Applicable, or Meet Intent, are mapped to SIS requirements presented in Section 7.4.

Table 7-1. Commentary on NUREG/CR-7253

Technical Area (NUREG/CR-7253)	Technical area applicability / reference requirement	Commentary
Section 1, 2, 3.1, and 3.2: Introduction, A brief history of seismic isolation, and Basics of Seismic Isolation	Not Applicable	There are no requirements or technical areas applicable as these are introductory and background sections.
<p>Section 3.3: The following qualification tasks should be accomplished before a new type of "three-dimensional SIS" is used.</p> <p>a) Dynamic testing full-scale (prototype) for beyond design ground motions (BDGM).</p> <p>b) Development of verified and validated numerical models.</p> <p>c) Demonstration that mechanical properties do not change by more than 20% over the design lifetime.</p> <p>d) System-level testing of the isolation system using three translational components of earthquake ground motion.</p> <p>e) Verification and validation of numerical tools used to predict response.</p>	<p>a) Meet Intent / 7.4.3.2, 7.4.4.8, 7.4.4.9, and 7.4.4.10</p> <p>b) Applicable / 7.4.2.2, 7.4.2.3 and testing requirements in (a)</p> <p>c) Applicable / 7.4.4.12</p> <p>d) Meet Intent / see commentary.</p> <p>e) Meet Intent / 7.4.3.8</p>	<p>a) Dynamic testing of the SIS is governed by the requirements of ASME QME-1 for the full range of expected parameters including the full range of external hazards defined using the RIPB design approach (see Section 7.7).</p> <p>b) Publications show excellent correlation of test data with a four-parameter Maxwell model [12] and [26] that only uses a combination of linear springs and viscoelastic dampers readily available through standard elements in typical software used in nuclear design such as SASSI, ANSYS, SAP2000, etc.</p> <p>c) Reference publications [27] and [28] show that spring rates do not change over time and remain within specification. Typical damper fluid testing shows high resiliency of damping properties which remain stable for gamma-radiation expected over the life of the plant. The damper fluid specified for the IDU will be qualified for the application specific radiation level.</p> <p>d) Publication [29], in a peer reviewed article, discusses system level testing with excellent predictive capabilities which meets the intent of this requirement. Additional examples are also available from the vendor.</p> <p>e) Computer codes such as SASSI, ANSYS, SAP2000, ABAQUS, etc. are or can be nuclear qualified and only use spring and viscoelastic damper elements. The three-dimensional SIS can be correctly represented by these elements in both linear or non-linear analyses.</p>

Technical Area (NUREG/CR-7253)	Technical area applicability / reference requirement	Commentary
	Not Applicable	The majority of the bearing and friction pendulum type isolation experience do not apply directly to three-dimensional SIS that use helical coil springs and viscoelastic dampers. Notable differences are that the three-dimensional isolation systems are a combination of linear springs and viscous dampers (non-hysteretic) with stable critical characteristics over the range of operating conditions (no rubber stiffening or inelastic deformation of lead core, etc.).
Sections 5 through 6: domestic and international codes and standards.	Not Applicable	<p>These sections provide an overview of applicable codes and standards for seismic isolation design applied to base isolated structures. The guidance is relevant for designing the building structures as well as selecting appropriate seismic hazard input. The section does not identify codes and standards that may be used for equipment seismic isolation systems such as the ASME BPVC or RIPB design process consistent with the NEI 18-04 approach. Note that under the ASME BPVC numerous dynamic restraints have been designed, qualified, installed and operated in the US (snubbers, dampers, and spring supports).</p> <p>The underlying performance assumptions of the cited standards rely on discrete design requirements for design basis and beyond design basis earthquakes without explicit evaluation of seismic risk resulting from the full range of external hazards, and the associated potential for cliff-edge effects.</p>
Section 7-1: Analysis of seismically isolated structures.	Applicable / 7.4.3.11	The four-parameter Maxwell model [12] and [26] that only uses a combination of linear spring and viscoelastic damper elements readily available through standard element types included with typical software used in nuclear design such as SASSI, ANSYS, SAP2000, etc. As a result, all three allowable approaches – coupled time-domain analysis, coupled frequency domain analysis, and multi-step analysis – are within the current capabilities of industry software. The three-dimensional SIS is modeled using linear springs and velocity proportional viscoelastic damper elements. If necessary, non-linear options of the same elements may be used to reproduce the test results of the SIS at the extreme displacement ranges.

Technical Area (NUREG/CR-7253)	Technical area applicability / reference requirement	Commentary
Section 7-2: Modeling of seismic isolator units, equivalent linear models, and non-linear models of isolators.	Meet Intent / 7.4.2.1, 7.4.2.2, 7.4.2.3, and 7.4.3.8	<p>The two-dimensional SIS technologies discussed in the regulatory guidance are distinctly different but the concept of modeling the critical characteristics can be applied to three-dimensional SISs.</p> <p>The mathematical (constitutive) model of the reactor SIS will be characterized using linear springs and viscoelastic dampers such as the Maxwell model [12] and [26]. The model parameters will be derived from the ASME Design Specification [15] and QME-1 [1] tests for the full range of seismic hazards, environmental conditions, and seismic load levels. Note that the constitutive model is inherently linear, so no linearization of the properties is required for design basis events. Frequency and amplitude dependency of the critical isolation parameters will be considered in developing the appropriate model parameters.</p> <p>For the full range of seismic hazards under NEI 18-04 [2], if necessary, non-linear models may be employed to assess the consequences and demonstrate vertical load carrying stability of the SIS. The non-linear constitutive models may use the available non-linear (spring and damper) finite elements and verified against test data. If a dynamic stop is necessary to mitigate the risk of low frequency seismic hazards the impact loads due to engaging the stop will be evaluated.</p>
Section 8.1: Philosophy in developing performance criteria.	Meet Intent / 7.4.2.4, 7.4.3.2, 7.4.3.4, 7.4.3.5, 7.4.3.7, 7.4.4.1, 7.4.4.2, 7.4.5.1, 7.4.4.4, 7.4.4.5, 7.4.4.8, 7.4.4.9, and 7.4.4.10	<p>The definition of Ground Motion Response Spectra+ and Beyond Design Basis Ground Motion Response Spectra do not align with NEI 18-04 [2] risk-target evaluations which require the assessment of the full range of seismic hazards as outlined via the methodology presented in Section 7.1.</p> <p>The three-dimensional SIS seismic risk is evaluated with considerations for singletons to determine appropriate seismic special treatments (such as stringent design criteria per ASME BPVC Section III, Division 5 [15]). Cliff edge effects and vertical load carrying capacity are included within the performance criteria and considered when establishing system critical characteristics. The ASME QME-1 [1] qualification addresses the displacement capacity of the SIS to meet NEI 18-04 [2] risk targets.</p>

Technical Area (NUREG/CR-7253)	Technical area applicability / reference requirement	Commentary
		<p>Prototype and production testing is included within the ASME specifications [15].</p> <p>Quality standards are applied by imposing both ASME NQA-1 [19] and NCA [3] (N-type certification).</p>
Section 8.2: Performance matrix, isolators and isolation system, foundation, umbilical lines, stop.	Meet Intent / 7.4.4.1, 7.4.4.4, 7.4.4.5, 7.4.4.7, 7.4.4.11, and 7.4.6.3	<p>The performance matrix provided in NUREG/CR-7253 is considered in developing the performance requirements for the SIS along with a RIPB approach to seismic design as described in Section 7.1. If the SIS extended displacement capacity is adequate to meet the RIPB target performance goal, then a stop may not need to be incorporated into the design irrespective of the remaining small residual risk of extremely low probability earthquakes.</p> <p>SSCs crossing the isolation boundary are qualified to the design basis relative displacement between the non-isolated and isolated structures. Requirements for SSCs crossing the isolation boundary will be established and qualified to industry standards. Per HFA-1110(g) [15] the rules of Subsection NF [17] do not apply to the dynamic stop except for the requirements as outlined in Section 7.1 (compression dynamic stops shall comply with NF-3000, NF-4000, NF-5000, and NF-8000). Seismic risk significance of SSCs crossing the isolation boundary will be considered in the process outlined in Section 7.2.</p>
Section 8.3: Hazard definitions for analysis of SIS.	Not Applicable	The design basis hazard level and full range of site-specific seismic hazards is established via the methodology described in Section 7.1.
Section 8.4: Performance expectations for ground motion response spectrum+ shaking.	Meet Intent / 7.4.4.1, 7.4.4.4, and 7.4.4.8	The Reactor SIS is designed to meet the SSE shaking design limit without damage to the isolators (i.e., essentially elastic response). The performance parameters of critical characteristics are described in the ASME Design Specification [15]. The ASME QME-1 [1] qualification addresses the full range of seismic hazards as well as operating environment. Prototype and production testing is included within the ASME procurement specifications.
Section 8.5: Performance expectations for beyond design	Meet Intent	a) Evaluation of the need for a stop is performed for the full range of seismic hazards using the approach presented in Section 7.1. If

Technical Area (NUREG/CR-7253)	Technical area applicability / reference requirement	Commentary
basis ground motion response spectrum shaking. a) Clearance to the stop b) Isolators c) Umbilical lines d) Stop	a) 7.4.4.4, 7.4.4.8, and 7.4.4.9 b) 7.4.4.5, and 7.4.4.10 c) 7.4.6.2, and 7.4.6.3 d) 7.4.3.7, and 7.4.4.11	necessary, dynamic stop(s) may be employed which may be placed outside the SSE displacement range plus margin to ensure unrestricted response of the system for design basis earthquakes. Dynamic stop(s) may not be needed if the SIS accommodates the extended displacement range to meet RIPB target performance goals. b) Requirements outlined in the ASME Design Specification [15] and associated testing under ASME QME-1 [1] ensure that the isolators maintain gravity load carrying capacity for seismic hazards derived for the NEI 18-04 [2] frequency-consequence (F-C) targets. Testing is carried out to demonstrate and characterize the failure mode of the SIS. c) Non-isolated systems connected to the reactor will be considered in risk evaluations, and if necessary, will be qualified to ensure the risk targets are met. d) If necessary, the impact due to a dynamic stop (characterized as “soft” or “engineered” stop) will be evaluated. Per HFA-1110(g) [15] the rules of Subsection NF [17] do not apply to the dynamic stop except for the requirements as outlined in Section 0.
Section 8.6: Seismic probabilistic risk assessment (SPRA).	Meet Intent / Inherent to NEI 18-04 [2] process	e) The reactor SIS is incorporated into the Natrium SPRA required for full implementation of NEI 18-04 [2], and it is an integral part of the assessment. The SPRA is updated periodically and also used to assess the reliability targets under the RIM program [25]. For additional details see Section 7.1.
Section 9.1: Additional considerations: a) long-term changes in isolator mechanical properties b) basemat and foundation design c) anchorage design d) other external events	a) Applicable / 7.4.4.12 and 7.4.5.2 b) Meet Intent / 7.4.4.13, 7.4.6.1, and 7.4.6.5 c) Meet Intent / 7.4.6.4, and 7.4.6.5 d) Meet Intent / 7.4.5.1	a) Environmental conditions and their effects are included with ASME Design Specification [15] and in the ASME QME-1 qualification specification [1]. The analysis of the SIS includes consideration for degraded conditions and the effect of environment. b) Due to the vertical flexibility of the three-dimensional SIS, sensitivity to differential settlement is greatly reduced. The smaller footprint of equipment isolation further reduces the risk associated with differential

Technical Area (NUREG/CR-7253)	Technical area applicability / reference requirement	Commentary
e) accident conditions and emergency response f) moat cap design g) near-fault ground shaking h) peer review	e) Meet Intent / 7.4.2.4, and 7.4.2.6 f) Meet Intent / 7.4.4.3 g) Meet Intent / see commentary h) Meet Intent / 7.4.3.1, 7.4.3.2, and 7.4.3.3	<p>settlement. Interfacing structures are designed to the same loads as the SIS.</p> <p>c) Interfacing components are designed to the same loads as the SIS. The anchorage design follows strict nuclear building codes and standards.</p> <p>d) The SIS is inherently protected by external hazards by being located inside the reactor building. Loads from the full range of internal and external hazards are mapped to ASME Service Levels and included in the ASME design specification.</p> <p>e) The ASME Design Specification [15] provides a complete set of Service Level conditions derived from the licensing basis of the plant to which the SIS will be qualified. In establishing the appropriate Service Level conditions severe accident, emergency response considerations and near-fault ground shaking considerations are included.</p> <p>f) The SIS is equipped with protective features to preclude debris contaminating the hydraulic fluid.</p> <p>g) Typical SIS fundamental frequencies range from 1 to 4 Hz in the lateral and vertical directions. These frequencies are considered sufficiently separated from the long period motions associated with the near-fault ground shaking. Near-fault ground motion is considered in the design of the plant and the in-structure response spectra (or time history) developed for the SIS.</p> <p>h) In accordance with ASME.BPVC.III.NCA [3] the design specification and design report of the SIS shall be certified by a certifying engineer. Qualification requirements of certifying engineers is included in ASME.BPVC.III Mandatory Appendix XIII which includes expertise in the entire construction process specific to the SIS including those identified for peer reviews in NUREG/CR-7253. Certifying engineers shall also be registered professional engineers. The certification is a separate independent process from other quality requirements and requires a certificate issued by ASME. Similarly, the ASME QME-1</p>

Technical Area (NUREG/CR-7253)	Technical area applicability / reference requirement	Commentary
		<p>specification and application reports are certified by a professional engineer providing adequate peer reviews.</p> <p>The reactor SIS is governed by the ASME BPCV Section XI, Division 2 RIM [4]. The RIM program addresses inservice inspections, monitoring and surveillance for the entire operating life of the plant. Degradation mechanism assessment (DMA) is performed so that RIM strategies may be identified that will detect the potential degradation mechanisms that are applicable to the SIS. The RIM program requires the establishment of two expert panels, the RIM expert panel (RIMEP) and the Monitoring and Nondestructive Examination (MANDE) expert panel (MANDEEP). The make-up of these panel ensures a thorough and comprehensive independent peer review of the SIS from all aspects of operations. The RIMEP and MANDEEP are provided with similar functions as an independent quality organization not reporting to the organization responsible for the design and construction of the SIS.</p>
Section 9.2: Additional manufacturing and construction considerations (quality control and quality assurance, testing of prototype and production isolators, construction assurance).	Meet Intent / 7.4.3.1, 7.4.3.2, 7.4.3.3, 7.4.3.4, 7.4.3.5, and 7.4.3.6	<p>Commensurate with the highest level of quality standards required for SR equipment the Reactor SIS is under both ASME NQA-1 [19] and ASME.BPVC.III NCA [3] (N-type certification). The ASME Code provides a set of standards that covers the entire lifecycle of the components from Design and Construction (ASME.BPVC.III), Qualification Testing (ASME QME-1 [1]), to inservice Operation (ASME.BPVC.XI.2 RIM [4]).</p> <p>The reactor SIS being an ASME component require appropriate certificate holders for the Design (N or NS - Certificate), Fabrication (NS-Certificate) and installation in a nuclear facility (NA certificate). The requirements of the ASME standards ensure that additional manufacturing and construction considerations are addressed.</p>
Section 9.3: Operation considerations: a) Inservice inspection, replacement and maintenance b) additional seismic monitoring equipment	a) Meet Intent / 7.4.3.3 b) Evaluated on a case basis c) Meet Intent / 7.4.3.10	a) The RIM program [4] requires the establishment of two expert panels, the RIM expert panel (RIMEP) and the Monitoring and Nondestructive Examination (MANDE) expert panel (MANDEEP). One of the MANDEEP members is an operations expert. Incorporating the RIM program development early in the design phase, issues such as access, probability of detection, and component reliability can be

Technical Area (NUREG/CR-7253)	Technical area applicability / reference requirement	Commentary
c) monitoring of foundation deformations d) requirements for safety-related equipment e) operating temperature	d) Not Applicable e) Not Applicable	<p>addressed and either design changes made or monitoring and NDE methods adapted accordingly to deliver a program that can be executed after plant start-up and ensure the reliability of components for the entire life cycle of the plant. Other items such as chemistry controls, periodic replacement, testing, operating limitations, fabrication practices may be utilized as part of the RIM strategies to ensure reliable performance throughout the component life cycle.</p> <p>b) The need for additional seismic monitoring equipment is evaluated on a case-by-case basis to be determined on implementation of the seismic isolation system.</p> <p>c) Position indicators are used to monitor deflection of the SIS units.</p> <p>d) SSC classification is performed in accordance with NEI 18-04 [2] as endorsed by RG 1.233 [11].</p> <p>e) NUREG/CR-7253 temperature limits are not applicable for the specific type of three-dimensional SIS. Temperature limits are established in the ASME Design Specification and qualified under ASME QME-1.</p>

7.4 Reactor Seismic Isolation System Requirement Allocation

Reactor three-dimensional seismic isolation performance criteria represent the set of requirements that the three-dimensional SIS must meet in order to provide assurance of acceptable performance. Requirements may be categorized as design constraints, functional, performance, and interface requirements. The requirements presented are elicited from the expected SIS safety classification, technical considerations applicable to reactor seismic isolation based on review of industry technical reports, and applicable codes and standards associated with the design and qualification of the SIS comprised of ISUs and IDUs. Compliance with requirements may be verified by one or more of the following methods:

- **Analysis:** The verification of a product/system using models, calculations, and/or testing equipment. Analysis allows someone to make a predictive statement about the typical performance of the product/system based on the confirmed results of a sample set or by combining the outcome of individual tests to conclude something new about the product/system. This can include analyses via analogy or similarity.
- **Inspection:** The nondestructive examination (NDE) of a product/system using one or more methods.
- **Demonstration:** The manipulation of the product/system as it is intended to be used to verify that the results are as planned or expected.
- **Acceptance Testing:** To establish that the unit is performing correctly and within predetermined tolerances.
 - The acceptance process may include inspections, testing, as well as other activities and shall be performed on SSCs produced. The acceptance test procedure shall be performed on qualification SSCs and other production SSCs, as well. The tests and other activities are intended to establish the SSC is performing correctly and within predetermined tolerances. The procedure shall include acceptance criteria.
- **Qualification Testing:** To establish that the SSC will perform its intended function under any foreseeable operating condition and shall be performed in accordance with an approved qualification test procedure.
 - The qualification process may include inspections, tests, analysis, other activities and shall establish, as far as practical, under laboratory conditions, that the SSC will perform its intended function under any foreseeable operating condition and shall be performed in accordance with an approved qualification test procedure.
 - Each qualification test is to be accomplished on an SSC(s), which is representative of future production SSCs. Qualification tests may be performed at the place of manufacture or by an approved testing laboratory.
 - The procedure shall include acceptance criteria.
 - Qualification test SSCs will generally not be acceptable for delivery as production SSCs unless approved; however, shipment of qualification test SSCs in as-is condition after

test completion for engineering evaluation or other use may be required. Test SSCs shall be maintained in “as tested” condition until disposition is approved.

7.4.1 Seismic Isolation System risk-informed performance-based requirements allocation strategy

In accordance with the RIPB seismic classification process outlined in Section 7.1 the SIS is classified as safety related (SR) and seismic risk significant (SRS) with the seismic special treatment categories and seismic special treatments summarized in Table 7-2. The special treatments planned to be applied to the SIS reflect the underlying intent presented in NUREG/CR-7253 [6] by addressing quality, construction, inspection, and operational standards, as well as cliff-edge effects.

Table 7-2. Seismic Isolation System Anticipated Seismic Special Treatment Category and Seismic Special Treatments

Seismic Special Treatment Category	Seismic Demand	Design Criteria
SR SRS: Safety Related, Seismic Risk Significant	SSE Local demands developed from seismic response analyses (site or building).	Structural design: <ul style="list-style-type: none"> AISC N690 (steel) [30] and ACI 349 (concrete) [31] Mechanical: <ul style="list-style-type: none"> Construction ASME.BPVC.III [32] and qualification ASME QME-1 [1]
SIS Seismic Special Treatment: <ul style="list-style-type: none"> Seismic isolation system shall exhibit no damage for SSE shaking. The isolated system shall be spaced at least at a distance from adjacent construction at the elevation of the isolator units equal to the maximum displacement necessary to achieve seismic target performance goal. <ul style="list-style-type: none"> If utilized any displacement stop shall be spaced at least at a distance equal to the maximum SSE displacement plus margin, such that it is free to displace without impedance up to this distance. Seismic isolation system shall retain gravity-load capacity when subjected to deformations consistent with the minimum distance to adjacent construction or the full compression of a displacement stop. 		

The performance-based design philosophy of the SIS enables the multi-objective search of design solutions that leverage risk insights with other design constraints and goals such as isolation frequency tuning, spatial arrangement, and inspectability. For instance, to minimize the cliff-edge effects the displacement of the SIS should be reduced by increasing the stiffness of the system which in turn would increase the acceleration response of the isolated system therefore reducing the safety margin on components. These are competing priorities and require careful balancing of the objectives. The SIS seismic special treatments align with the NEI 18-04 [2] event classification derived from the NEI 18-04 [2] F-C target which at a high level consists of two groups, licensing basis events and other quantified events. In terms of the SIS development, the high-level performance expectations are summarized in Table 7-3.

Table 7-3. Seismic Isolation System performance expectations

	Licensing basis events		
	AOO	DBE	BDBE
Performance expectation	Essentially linear response no damage to SIS	Essentially linear response no damage to SIS	Limited non-linear response limited damage to SIS
	Retain gravity-load capacity		
	Redundant system and stringent reliability target		

The third element in establishing the SIS requirements is to consider the performance envelope of the SIS which is mapped to the event classes of NEI-18-04 and performance expectations of Table 7-3. The SIS is primarily characterized by its stiffness (force displacement relation), displacement capacity and the viscous damper coefficient. The requirements and qualification program focuses on ensuring:

- Directional stiffness (horizontal and vertical) of the spring elements for LBEs is within prescribed values.
- Vertical gravity load stability of springs is demonstrated for LBEs with or without a dynamic stop.
- Failure mode testing of springs (may be used as basis to determine if a dynamic stop is needed) is performed.
- Amplitude and frequency dependent damping and stiffness characteristics of IDU for DBE is determined within the specified range.
- Characterization of IDU stiffness and damping and demonstration of unrestricted motion including BDBE displacement are completed.
- Failure mode testing of IDU is performed.

The SIS performance envelope is graphically represented in below. The figure provides a simple interpretation to guide the qualification and testing requirements that serve as the basis for demonstrating acceptable performance for the full range of NEI 18-04 [2] events (DBE, and BDBE for the licensing basis events, and considers DBE performance to envelope AOO performance, and FM for the other quantified events). The black square in the figure represents the initial condition of the ISU (e.g., static vertical deflection due to dead weight for the springs, the horizontal initial state is indicated at the zero location, but it could be adjusted to capture relative thermal displacement as the reactor heats-up). The initial state of the IDU can be considered at zero for both horizontal and vertical directions (note that dampers can be installed to account for the static deflection of the springs and relative thermal movement to attain a nominally zero ordinate and abscissa location).

The springs are tested to the DBE, BDBE and FM limits by imposing horizontal displacements (displacement controlled) with simultaneous application of vertical forces (force controlled) for each performance state. Using this testing sequence allows for verifying the theoretical stiffness in each direction, any coupling between the directional stiffness, and assessing vertical gravity load carrying stability.

The IDU is tested to the DBE, and BDBE limits by dynamically imposing horizontal and vertical displacements (displacement controlled) over the range of amplitudes and frequencies. During the FM testing of the IDU the loading is force controlled providing the force-deflection characteristics that can be used to assess the other quantified events.

Testing is performed using quasi-static and dynamic signals (usually a modified sine-wave or four-cycle-beat) derived from the maximum displacements for each performance range as needed. The ISU static and dynamic properties are invariable in the frequency range of interest therefore the quasi-static testing alone is adequate. The enclosed area of the hysteresis loops recorded during the IDU dynamic tests are used to measure the dissipated energy and damping coefficient (amplitude and frequency dependent). The following sections outline the requirements that constitute the design basis and lifetime performance characteristics of the Sodium three-dimensional reactor SIS.

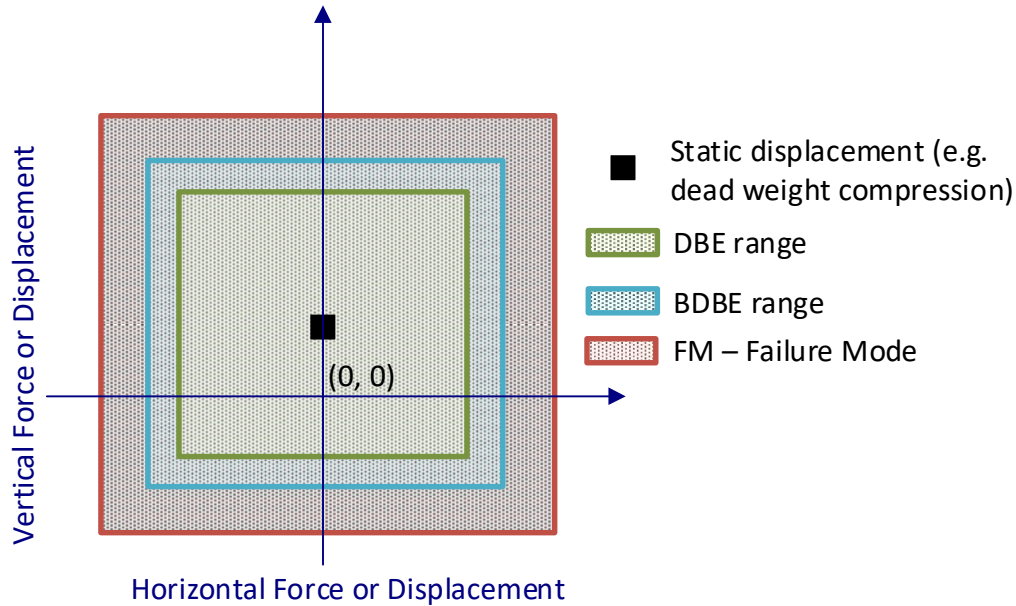


Figure 7-4: Seismic Isolation System performance envelope

7.4.2 Functional Requirements

7.4.2.1 Seismic Isolation Direction

The SIS shall be effective in the three orthogonal directions (vertical and horizontal, i.e. three-dimensional seismic isolation).

Rationale: Advanced reactors operating at high temperatures and at near atmospheric pressure utilize structures that require reduced thickness to manage loads, resulting in relatively flexible structures. Head mounted advanced reactors benefit from seismic attenuation in all spatial directions.

7.4.2.2 Seismic Load Attenuation for SSE

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7.4.2.3 Seismic Load Attenuation for BDBE

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7.4.2.4 Seismic Isolation System Operation

The SIS shall require no external power or control for licensing basis and other quantified events.

Rationale: Consistent with passive advanced reactor design objective.

7.4.2.5 Seismic Isolation System Vertical Load Path

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7.4.2.6 Seismic Isolation System Centering

The SIS shall provide sufficient restoring force to re-center the supported SSCs within acceptable tolerance after an SSE.

Rationale: Recentering safety significant SSCs after an SSE is desirable to maintain configuration of SSCs relative to each other.

7.4.2.7 Seismic Isolation System Service Life

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7.4.3 Design Constraint and Quality Requirements

7.4.3.1 Seismic Isolator Construction Code

The SIS shall conform with the requirements of ASME Boiler and Pressure Vessel Code, Section III, Division 5, Subsection HF, 2017 Edition.

Rationale: RG 1.87 [16] endorses ASME.BPVC.III.5 “High Temperature Reactors” [15] as an acceptable means to meet regulatory expectation for SSCs. The Seismic Isolators fall within the jurisdictional boundary of ASME.BPVC.III.5, Subsection HF, Class A and Class B Metallic Supports, 2017 Edition.

7.4.3.2 Seismic Isolator Qualification

The SIS shall be qualified in accordance with ASME QME-1, 2023 Edition.

Rationale: The purpose of ASME QME-1, Qualification of Active Mechanical Equipment Used in Nuclear Facilities, [1] is to provide requirements to qualify mechanical equipment based on functional and critical characteristics requirements for licensing basis events. The Reactor SIS falls under the qualification program of ASME QME-1. Section QDR of ASME QME-1 provides rules for qualification of dynamic restraints and section QR discusses the associated general

requirements. The boundaries of jurisdiction of ASME QME-1 align with those defined in ASME.BPVC.III.1, Subsection NF and governed by QDR-1100.

7.4.3.3 Seismic Isolator Reliability and Integrity Management

The SIS shall conform with ASME BPVC, Section XI, Division 2, 2019 Edition for monitoring, inservice inspections, and surveillance for the entire operating life of the plant.

Rationale: The SIS is required to maintain reliability over the life of the plant which include operational considerations for inservice inspection, replacement and maintenance. The Reliability and Integrity Management (RIM) Program provides direction for assuring the reliability and integrity of passive components whose failure could adversely affect plant safety and reliability. The RIM Program is outlined in the ASME BPVC, Section XI, Division 2, "Requirements for Reliability and Integrity Management (RIM) Programs for Nuclear Power Plants". The 2019 Edition of this code is endorsed by the U.S. NRC in RG 1.246 [25].

7.4.3.4 Seismic Isolator Quality Assurance

The SIS shall comply with ASME NQA-1 2015 Edition, Quality Assurance Requirements for Nuclear Facility Applications [19] and 10 CFR 50, Appendix B [14].

Rationale: Commensurate with the SIS safety significance and seismic risk significance imposing the most stringent quality provision provides assurances for the highest standards in manufacturing, construction, installation, operation over the life-cycle of the plant.

7.4.3.5 Seismic Isolator Fabrication

The SIS fabricator shall have an issued and active ASME NS-Certificate for construction of supports.

Rationale: Certificate holder responsibilities are included in ASME.BPVC.III, Subsection NCA-3200 [3]. Commensurate with the SIS safety significance and seismic risk significance imposing the most stringent quality provision provides assurances for the highest standards in manufacturing, construction, installation, operation over the life-cycle of the plant.

7.4.3.6 Seismic Isolator Installation

The SIS shall be installed in the plant by a Supplier that has an issued and active ASME NA and/or NS-Certificate.

Rationale: ASME.BPVC.III. NCA-1282 [3] provides requirements for support installation certificates. Commensurate with the SIS safety significance and seismic risk significance imposing the most stringent quality provision provides assurances for the highest standards in manufacturing, construction, installation, operation over the life-cycle of the plant.

7.4.3.7 Seismic Isolator Stop Design

Compression spring end plates and compression dynamic stops shall conform with ASME.BPVC.III.1 Subsection NF, Articles NF-3000, NF-4000, NF-5000, and NF-8000.

Rationale: If used, compression dynamic stops used as stops do not need to meet the requirements of ASME.BPVC.III.1, Subsection NF with the exception of the code articles as described in ASME.BPVC.III.5 HFA-1110(g)(8 and 9).

7.4.3.8 Seismic Isolator Parameters

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7.4.3.9 SIS Material of Construction Flammability

The SIS shall use non-combustible materials for construction.

Rationale: To reduce risk of fire in proximity to safety significant components construction materials should be non-combustible.

7.4.3.10 SIS Inservice Position Indication

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7.4.3.11 Seismic Isolator Analysis Methods

The SIS analysis shall conform to the analysis methods outlined in ASCE 4-16 [33].

Rationale: The criteria for seismic analysis outlined in ASCE 4-16 industry consensus standard is applicable to the Sodium seismic analyses.

7.4.4 Performance Requirements

7.4.4.1 Seismic Isolator Reliability for SSE

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7.4.4.2 Seismic Isolation Redundancy

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7.4.4.3 Seismic Isolator Debris Exclusion

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7.4.4.4 Seismic Isolator Displacement Capacity

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7.4.4.5 Seismic Isolator Extended Displacement Capacity

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7.4.4.6 Seismic Isolator Uplift

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7.4.4.7 Seismic Isolator Displacement Clearance

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7.4.4.8 SSE SIS Testing

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7.4.4.9 Licensing Basis Events SIS Testing

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7.4.4.10 SIS Failure Mode Testing

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7.4.4.11 Impact Assessment of Dynamic Stop

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7.4.4.12 Seismic Isolators Long-Term Performance

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7.4.4.13 Seismic Isolators Differential Settlement

The SIS analysis shall address short-term, and long-term effects of differential settlement of the soil and foundation flexibility.

Rationale: Differential settlement of the foundation could result in uneven loading of the isolators and redistribution of loads that could lead to failure of the SIS.

7.4.5 Environmental Requirements

7.4.5.1 Seismic Isolator Protection against External Events

The SIS shall be protected against or designed for, fire, high winds, flood and other hazards consistent with the licensing basis of the plant.

Rationale: Safety-related equipment shall meet performance expectations for external events.

7.4.5.2 Seismic Isolator Environmental Conditions

The SIS design shall accommodate environmental degradation due to aging effects, creep, fatigue, operating temperature, radiation and exposure to moisture or damaging substances.

Rationale: Appropriate environmental conditions shall be accounted for in accordance with ASME.BPVC.III.5 [15], ASME QME-1 [1], and ASME.BPVC.XI.2 [4], for the construction, qualification and life-time operation of the SIS.

7.4.6 Interface Requirements

7.4.6.1 Seismic Isolator Interfacing Structures

Structures directly interfacing with the SIS shall be designed with adequate rigidity to ensure all seismic isolators are engaged.

Rationale: The interfacing support structures should be stiff enough to ensure even load distribution between the SIS units. Stiff interfaces ensure that failure of a single isolator does not result in significant load redistribution.

7.4.6.2 Isolated SSCs Clearance to Non-isolated SSCs

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7.4.6.3 Umbilical Lines Crossing the Isolation Interface

Safety-significant umbilical lines and their connections across the isolation interface shall be shown to accommodate the maximum displacement of the SIS.

Rationale: Ensuring adequate displacement capacity of umbilical lines at the isolation interface to mitigate adverse interaction.

7.4.6.4 Interfacing SSCs Redundancy

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7.4.6.5 Interfacing SSCs Loads

SSCs directly interfacing with the SIS shall be designed for loads developed in the SIS corresponding to its maximum displacement or impact loads due to engaging a dynamic stop.

Rationale: Ensuring that the anchorage and support structure design at the interface is robust to transmit the loads through the interface by not presenting a weak link is necessary.

7.4.6.6 Attachment to Interfacing Structures

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7.5 Reactor Seismic Isolation System Design and Analysis Methods

The SIS key dynamic characteristics include its stiffness and damping. These characteristics are tuned by analysis and validated by testing to meet the functional and performance requirements. The SIS must also maintain practical dimensions to accommodate space allocation in the RXB and reduce design constraints. The main consideration in tuning the spring stiffness is a compromise between limiting deflections between the isolated and non-isolated structures, while maximizing the attenuation of accelerations over the frequency range of interest of the seismically isolated systems. The SIS displacement capacity must also be sufficiently large to accommodate the required range of deflection and additional safety margin, while maintaining structural integrity and stability.

Analyzing SIS performance requires the development of numerical models to resolve the demand on the SIS components and supported subsystems. Acceptable modeling approaches can include single or multi-step analyses, depending on the computational resources and required resolution of the models. In the single step approach, a detailed dynamic representation of the building, SIS and supported subsystems is included. In the multi-step approach, simplified, dynamically equivalent models are used to reduce the computational demand. The following sections provide additional overview of the scope of the models depending on the modeling approach.

7.5.1 Single Step Analysis Process

In the single step, a single numerical model is used to represent the dynamic response of the reactor building and interaction between the soil and its foundation. This model includes a detailed representation of the SIS and seismically isolated systems. SSCs included in the single step analysis are modeled at sufficient details to accurately capture the dynamic response of SSCs and allow

resolving demand on subsystems supported by the SIS, without the need for handoffs of motions between different models or software. A single-step analysis can be solved in the frequency domain, if the response of the SSCs can either be accurately simulated or bounded using linear analyses. Time history analysis can also be used for the single step approach, if non-linearities are introduced by the response of SSCs to seismic shaking, or if time-history demand is required for seismic qualification of SSCs.

7.5.2 Multi-Step Analysis Approach

To illustrate the multi-step approach, an analysis process diagram is shown in Figure 7-5. The features that distinguish the multi-step from the single step approach are the use of simplified, dynamically equivalent models to represent subsystems during different stages of the analysis and, the need to handoff of seismic demand between different models. The main steps used for the multi-step analyses process in Figure 7-5 are as follows:

1. A simplified dynamically equivalent model is created to represent the dynamic characteristics of seismically isolated subsystem. The simplified model is calibrated to simulate with sufficient level of conservatism the effective mass which participates at the fundamental mode of the detailed model. The model shown on the right of Figure 7-5 represents the reactor core but may be used for any SIS supported subsystem.
2. An integrated subsystems model is created as shown on step 2 of Figure 7-5. This model may include a combination of explicit representation of subsystems, such as the metallic core support shown, and simplified subsystems, such as the reactor core. This model includes a detailed representation of the SIS and accounts for the fluid-structure interaction on submerged components. A simplified representation of this model is created for incorporation in the RXB model. The simplified model is tuned to accurately represent the relation between modal frequency and effective mass up to and over accumulated 90% of the effective mass, in both the translational and rotational motions. A good agreement between the simplified and detailed models in the translational and rotational motions ensures that rocking motions and associated effects are accurately represented in the SSI.
3. Reactor building dynamic structural model appropriate for soil-structure interaction analysis that includes the RXB structural model, representations of dynamically significant subsystems, and applicable loading and stiffness properties per ASCE 4-16 [33]. The isolated subsystems are represented by simplified model from the previous step. The RXB soil-structure interaction analysis is performed and provides the in-structure motions at the base of the SIS as input into subsequent response analysis.
4. The in-structure motions at the base of the SIS are smoothed, broadened and local valleys are filled consistent with RG-1.122 [34] or ASME [35] N-1226.3, if response spectrum is used. The guidance of ASME [35] N-1222.3 is used if time-history analysis is used. These motions are applied to the model developed in step (2) and include at a minimum three components of orthogonal translational motions. Two components of rotational (rocking) motions must be included, if shown to be significant by interrogating the model used in step (3).
5. Seismic analysis of RES subsystems which were represented as simplified, dynamically equivalent include similar considerations to step 4. Motions should be broadened and enveloped to account for modeling simplification associated uncertainties. When subsystems are supported

at multiple locations, the rules of ASME [35] N-1227 should be followed to ensure correct application of loads. If the subsystems are submerged in liquid, fluid-structure interactions must be considered at this level as well.

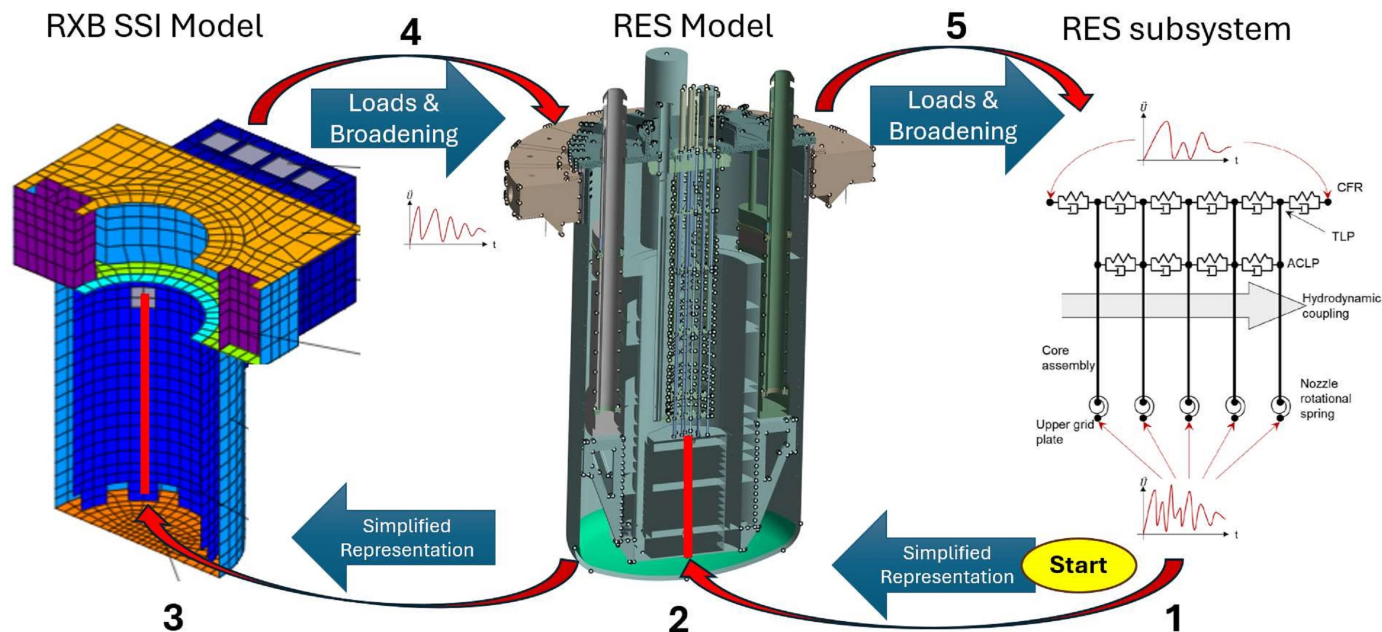


Figure 7-5: Example of multi-step seismic analysis process.

7.5.3 Variation of Seismic Isolation Properties

SIS key dynamic characteristics are established by testing consistent with the requirements outlined in Section 7.7. Target nominal values for SIS components stiffness and damping, as well as acceptable deviation from these values are controlled by the SIS ASME Design Specifications. Should the deviation between the nominal and actual properties, over the Service Life of the components, be greater than accounted for by following RG-1.122 [34], additional broadening must be implemented to ensure sufficient conservatism in the seismic demand.

As was shown in Figure 7-6, the SIS is mounted to a stiff concrete slab, which ensures significant dynamic decoupling between the supporting and supported subsystems. Due to this decoupling, the effects of SIS property variability on the SSI analysis results and motion profile at the base of the SIS is negligible per the diagram of ASCE 4-16 Figure 3-2 [33]. As shown in Figure 7-6 below, the SIS properties included in the SSI model may only be the nominal properties which are established by the SIS qualification process and enforced by the ASME Design Specifications. However, the variation in demand on the SIS components and supported subsystems must be enveloped based on analyses utilizing the inputs from analysis step 3 and, variations of the SIS properties within the expected range over its service life as permitted by the SIS Design Specifications.

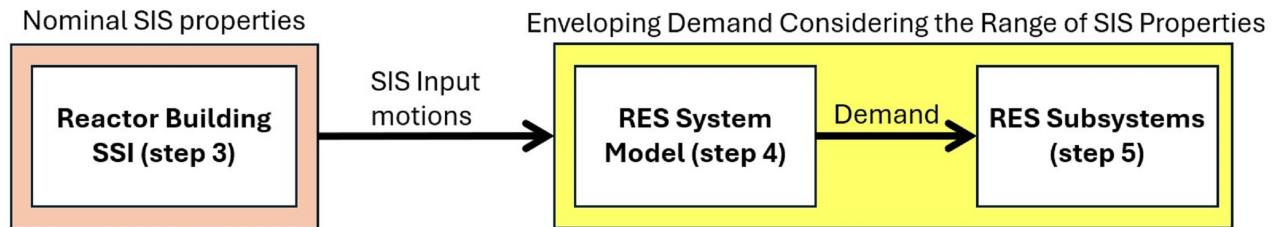


Figure 7-6 Accounting for variability in SIS properties of demand on SIS supported Subsystems

7.6 Reactor Seismic Isolation System Design and Construction

As outlined in Section 7.2, the SIS components are ASME.BPVC.III.5 HFA standard supports, designed and constructed under the rules of ASME.BPVC.III.1, Subsection NF. Per NF-3411.1, standard supports can be used as component supports, such as the supports for the RV. The ASME Code is a construction code, which means that it covers the entire lifecycle from Design through Installation by providing a complete set of rules for construction (design, materials, fabrication, testing, examination, and installation). The specific ASME activities applicable during the construction of the SIS are shown in Figure 7-7. In order to perform any ASME activities, an organization shall obtain and maintain an appropriate ASME certificate of authorization. The various N-type Certification of authorizations (N-Certificates) necessary for the construction of the SIS are shown in Table 7-4.

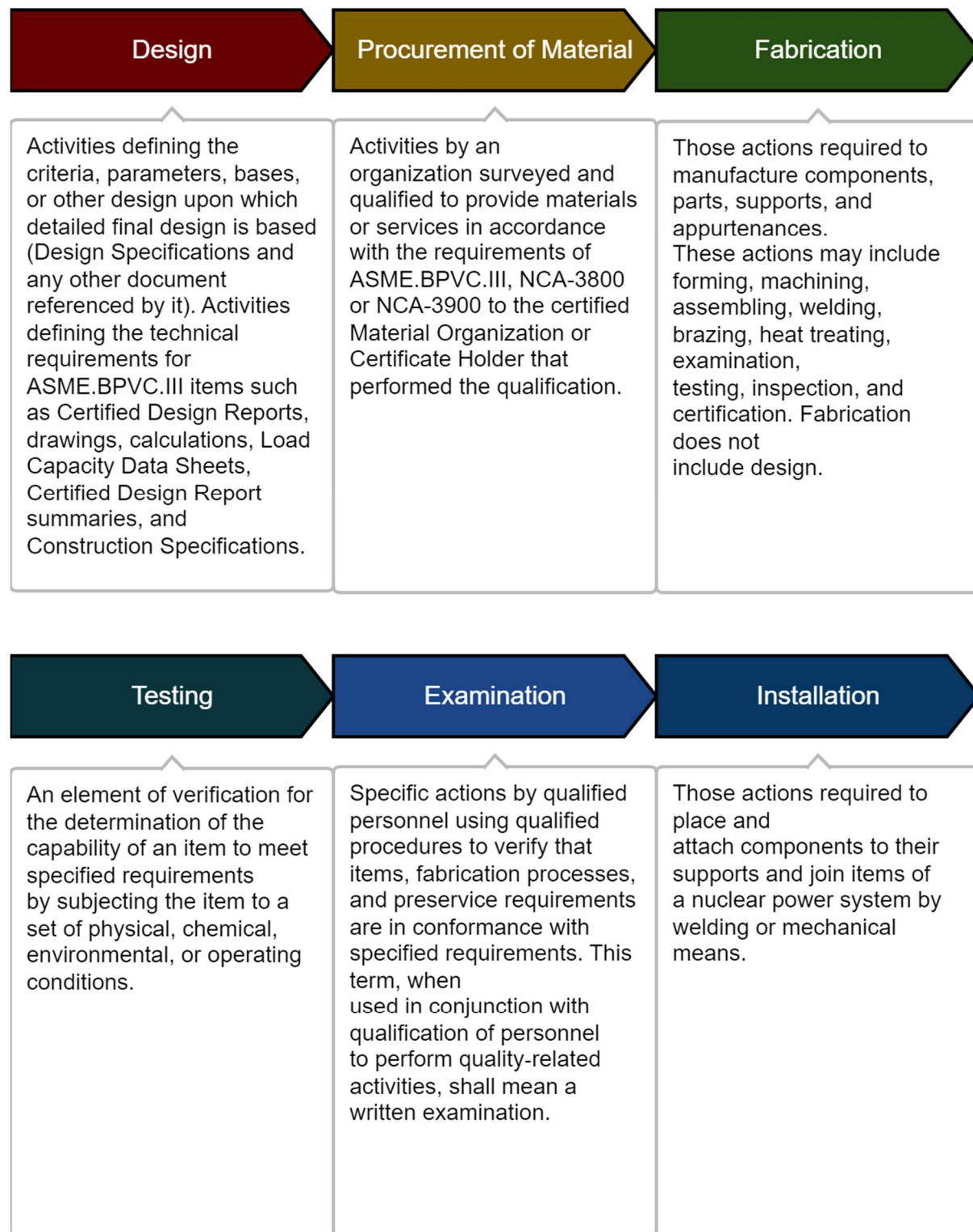


Figure 7-7. ASME BPVC Section III Nuclear Facility Construction Activities [3].

Table 7-4. ASME Issued N-Type Certificates and Scopes Necessary for SIS

N-type Certificate	Description
N	Construction of vessels, pumps, valves, piping systems, storage tanks, core support structures and concrete containments – maintains overall design responsibility
NA	Field installation and shop assembly of all items
NS	Fabrication of supports with or without design responsibility
OWN	Nuclear power plant Owner
QSC	Manufacture and supply of material

In accordance with ASME.BPVC.III NCA-1233, the Design Conditions of the SIS shall be included in the Design Specification. In addition, a Design Report, Load Capacity Data Sheet, or Design Report Summary shall be furnished. Certification of the documents shall be as required by ASME.BPVC.III NCA-8000. The Owner (or if designated, the N-Certificate Holder) has the overall design responsibility. The N-Certificate holder is responsible for compiling all lifetime and non-lifetime quality records and turning them over to the Owner. Where certification of documents is required, it shall be provided by certifying engineers (CE) meeting the qualification requirements of ASME.BPVC.III Mandatory Appendix XXIII [3].

As the SIS is classified as standard supports, an NS-Certificate is required for the fabrication of the ISU and IDU. Installation of the SIS shall be in accordance with ASME.BPVC.III NCA-1282 which consists of those activities required to attach the SIS to the building structures and other reactor support structures. The installation shall be performed by an NA-Certificate holder at the location authorized by its certificates. Specific responsibilities of certificate holders are in ASME.BPVC.III NCA-3211. Items constructed in accordance with ASME.BPVC.III shall be inspected by Authorized Inspection Agency (AIA) accredited by ASME. Certificate holders shall enter into a written agreement with an AIA as stipulated in NCA-3200.

7.7 Reactor Seismic Isolation System Qualification

The reactor SIS is an active mechanical equipment in accordance with ASME QME-1 [1] because it must undergo mechanical movement in order to accomplish its required function. The SIS consists of separate ISUs and IDUs as described in Section 6. The qualification program applies to both with consideration of the specific characteristics of the seismic isolation units. The qualification augments the requirements of ASME.BPVC.III.1 Subsection NF.

Qualification of the SIS follows the process described in ASME QME-1 QR General Requirements. The qualification process for the SIS is illustrated in Figure 7-8 conforming to the qualification principles outlined in ASME QME-1.

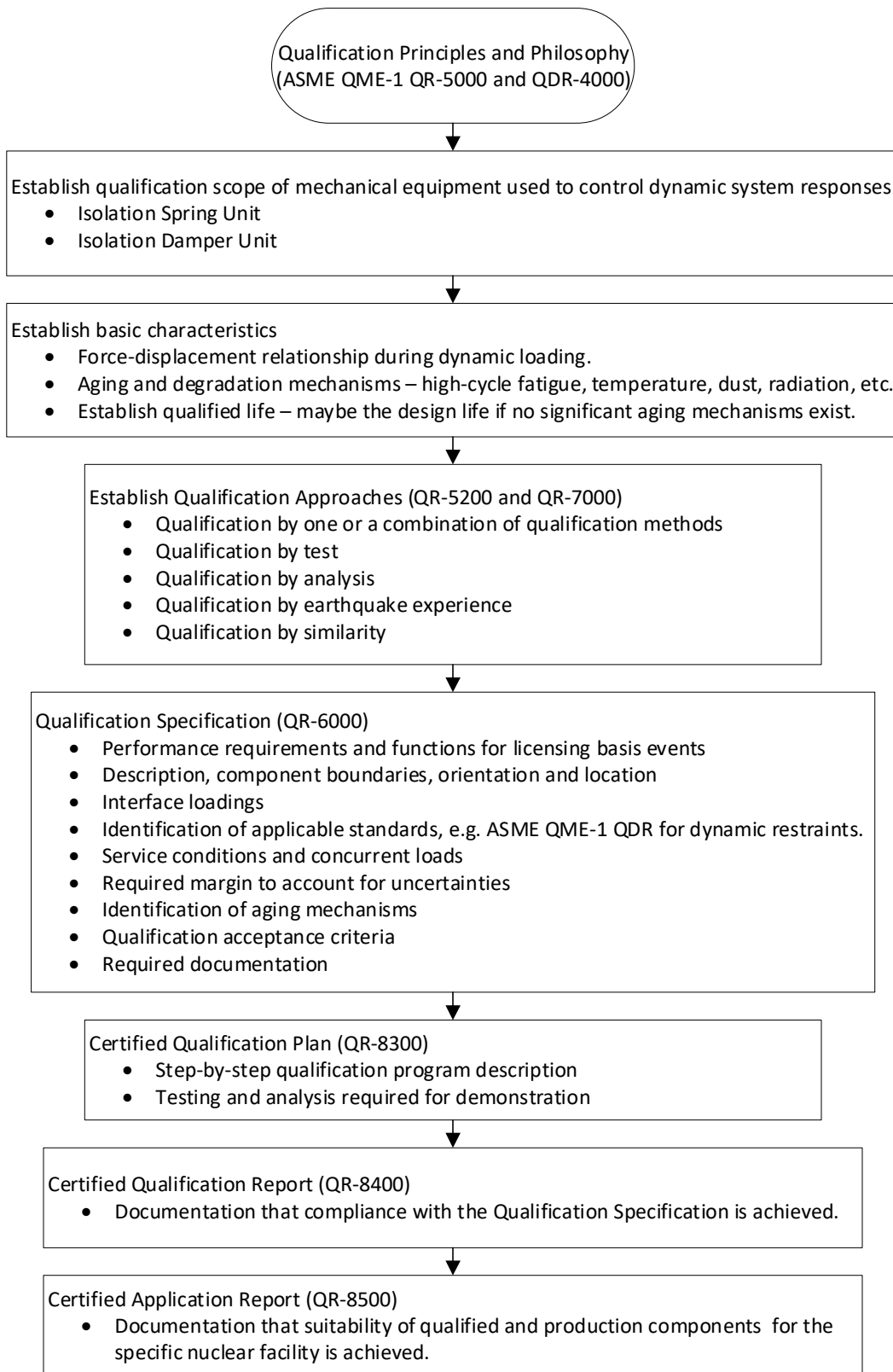


Figure 7-8. Seismic isolation system qualification program development

7.7.1 Qualification principles and specification

The ISUs are most similar to the gap restraints described in ASME QME-1 QDR-4300 with the following differences:

- There are no gaps that must be closed for the ISUs to accommodate thermal movements of the reactor. The ISUs are rigidly attached to the building and reactor support structure.
- The ISUs are inherently linear devices for design basis events with identical tension/compression load resistance irrespective of the direction of movement.

Due to the construction (no gap) and linear behavior of the ISUs, the functional parameters applicable per ASME QME-1 QDR-4310 are:

- The spring rate (QDR-4310(b)) – The required spring rate is determined by analysis as described in Section 7.5. Deflections are imposed on the ISUs due to static and dynamic loads. The manufacturer shall establish the spring rates by means of testing. Springs rates are defined in the horizontal and vertical directions, and they are validated for the full range of displacements. Spring rate tests may be specified that apply the displacements in the respective directions alone and in combination to determine if any coupling between the directional spring rates need to be accounted for.
- Fatigue of spring (QDR-4310(c)) – Fatigue life of the springs may be determined either by testing or analysis or a combination.
- Drag (QDR4310(d)) – for completeness drag is negligible and therefore not applicable due to the inherent design and application of the ISU.
- Load rating (QDR-4310(e)) – Load rating maybe determined by test or analysis or a combination in accordance with ASME.BPVC.III.1 Subsection NF [17].

The functional parameters identified above are the minimum set and the Qualification Specification may identify additional ones as necessary.

The IDU is a viscoelastic damper and the functional parameters of QDR-4400 are applicable. Characteristics of the dampers is that they develop force-displacement/velocity relation during dynamic events, restraining the SSCs during seismic, operational vibration, or any other impact or impulse loads. Under static or non-dynamic events, the movement in the dampers result only in a very small fraction (negligible) restraining drag force of the rated load capacity. Stiffness and damping parameters of the damper are functions of the damping fluid viscosity (temperature and radiation dependent), the rate and frequency of applied loading, and displacement. Based on these characteristics the essential functional parameters of the dampers are:

- Drag (QDR 4410(a)) – Drag is the force required to move the damper piston at a specific velocity. Testing shall be conducted to measure the horizontal and vertical drag force at varying velocities.
- Rated Load (QDR 4410(b)) – The rated load of the damper shall be determined by test and analysis in accordance with ASME.BPVC.III.1 Subsection NF [17]. If cavitation is a potential phenomenon for cyclic loading, then it shall be determined and identified in the qualification report (QDR-7310).

- Spring Rate Stiffness (QDR 4410(c)) – Spring rate stiffness shall be determined by dynamic testing as a function of frequency or velocity of the applied load. Methods of spring rate stiffness determination shall be identified in a Qualification Report.
- Damping Resistance (QDR 4410(d)) – Damping resistance shall be determined by dynamic testing as a function of frequency or velocity of the applied load. Methods of damping resistance determination shall be identified in a Qualification Report.
- Allowable Displacement (QDR 4410(e)) – The allowable displacement range of the damper is a parameter established for the damper. Testing should be carried out over the range of allowable displacement range.

A qualification specification shall be furnished for the SIS in accordance with the requirements of ASME QME-1 Mandatory Appendix QDR-I. The qualification specification shall be provided by the Owner (or designee) or the restraint manufacturer with Owner's approval. The qualification specification provides the details of functional requirements and its minimum content shall conform to QDR-I as shown in Figure 7-9.

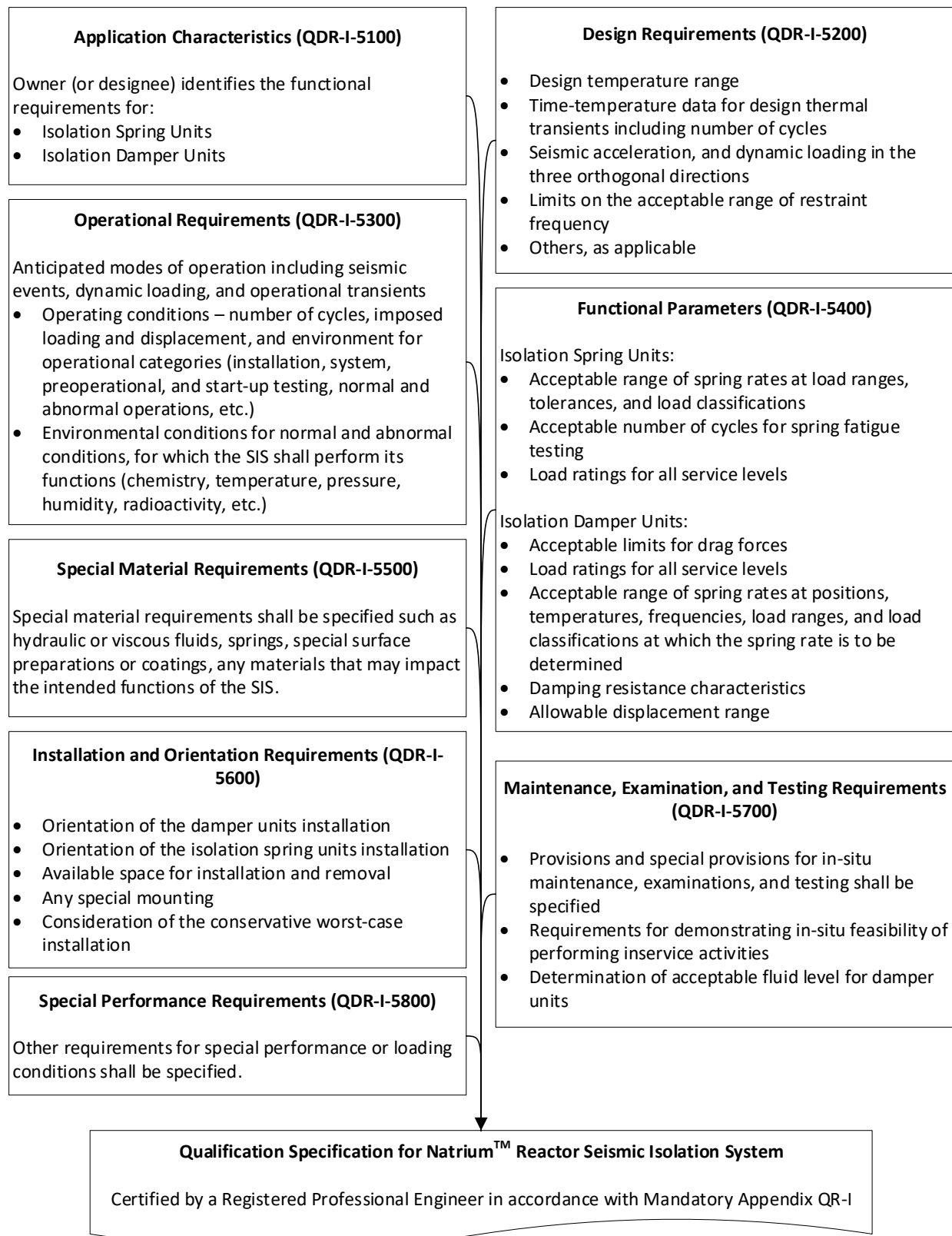


Figure 7-9. Qualification specification minimum content

7.7.2 Qualification Program

Qualification of the SIS may utilize two basic methods in accordance with ASME QME-1 QDR-6100.

- The SIS may be qualified by a program of testing and analysis to become a qualified parent SIS using sub-article QDR-6200.
- The SIS may be qualified by an extension of a qualification program that has been previously performed on a similar parent restraint using sub-article QDR-6300.

If adequate previously performed qualification program is not available, the Natrium demonstration plant may utilize the parent qualification process while subsequent installations at other sites may utilize the candidate qualification process based on the qualified Natrum parent SIS. An important element of qualification approaches is the qualification by similarity (QR-7340 and QDR-A). In order to demonstrate the SIS for the full range of licensing basis events, including beyond design basis events, qualification by similarity and analysis maybe necessary due to the limitation and impracticality to test the SIS at full scale. The similarity qualification process is based on a high degree of similarity regarding the design, configuration, materials, dimensions, tolerances, surface finish, fabrication and assembly method, coating and plating, and production testing. Similarity shall be established considering the functional and other parameters in the qualification specification of the candidate unit. In all cases the similitude is established in a conservative manner to account for scaling distortions and uncertainties.

7.7.2.1 Parent Qualification

Program elements for parent qualification of the SIS is in accordance with ASME QME-1 QDR-6200. Each element applicability is briefly described in the following paragraphs.

Approach to qualification:

Parent qualification provides the generic qualification of the reactor SIS documented in the Application Report for its specific application. The number of units or sample set selected for qualification shall be established by the Owner accounting for uncertainties and for added conservatism. Root cause analysis of any failure shall be provided that serve as the basis for design changes.

Testing:

The SIS qualification plan specifies the functional parameters and environmental variables subject to testing as established in the qualification specification. The spring rate may be dependent on load direction, travel, amplitude and frequency of dynamic loading and environmental conditions. Appropriate dynamic testing over an appropriate range of frequency and amplitude is performed. The following elements shall be considered for testing:

- Installation and Orientation
 - The qualification plan specifies the mounting means for parent testing. Mounting shall represent the expected service application and allow for adequate instrumentation and monitoring.
- Test and Monitoring Equipment
 - The test shall be adequately instrumented to record monitored variables. Test and monitoring equipment shall be sufficiently calibrated and documented and its accuracy

verified within the anticipated range. Data sampling shall be sufficient to capture the highest frequency of interest.

- Test Sequence

- The test sequence shall follow the steps described below. Any deviations from this sequence shall be justified in the qualification report. Additional testing may be inserted within this sequence as appropriate.
 - a) Pretest examination (thorough dimensional examination of components documented baseline for post-test dimensional examination comparison).
 - b) Pre-aging functional parameters testing.
 - c) Aging and service condition simulation.
 - d) Intermediate examination without disassembly, maintenance, or modifications (visual examination for loose, broken, or corroded components, fittings, fasteners, etc.; any fluid loss shall be noted).
 - e) Post-aging functional parameter testing.
 - f) Post-test examination.

- Functional Parameter Testing for ISUs

- Dynamic cyclic load testing equal to the rated load (or other specified load) shall be used to verify the spring rate.
- The fatigue life of the springs shall be verified by test by applying sufficient number of cycles that simulates the expected design life.
- A Service Level D loading amplitude shall be applied to the springs and the force, displacement, and velocity shall be recorded. Any damage or other anomalies shall be noted and evaluated to assess the effects of Service Level D loads on the operability of the ISUs.

- Functional Parameter Testing for IDUs

- Viscosity of the damper fluid shall be recorded as a function of temperature. The temperature at which the IDU ceases to perform its intended function (loss of viscosity) shall be recorded. When damping function is lost the damper can effectively act as a gap support (or soft stop) and a separate qualification as a gap support may be required.
- Drag force associated with moving the piston with applied rated load (displacement) over a range of velocities and various temperatures shall be measured and documented.
- Rated loads for applicable ASME Service Levels shall be defined.
- Dynamic spring rate of the damper for active degrees of freedom shall be measured as a cyclic load at 0.1 Hz (effectively static load) and at increments in the frequency range as specified in the Design Specification and documented in the Qualification Report.

- The spring rate at various temperatures shall be verified and documented.
- Dynamic spring rate curves as a function of different levels of rated cyclic load/displacement at incremental frequencies shall be verified and documented as specified in the Design Specification and Qualification Report.
- From the damper spring rate curves, a representative stiffness shall be developed and documented to define damper elastic stiffness.
- Damping resistance characteristics for cyclic load, size, and temperature as required for stiffness evaluation shall be determined and documented.
- Aging and Service Condition Simulation
 - Aging simulation based on environmental conditions for the design life of the SIS shall be specified in the qualification plan in accordance with the requirements in the qualification specification.
 - Service condition simulation (humidity, temperature, etc.) shall be specified in the qualification plan. The service conditions applicable to service level events such as vibration aging, operating basis earthquake, safe shut down earthquake, pipe break, etc. shall be considered as specified in the qualification specification.
- Special Tests
 - The qualification plan shall specify any special tests for the SIS to meet the requirements in the qualification specification. These special tests may extend into the BDBE earthquake level and shall consider the applicable service conditions or failure mode of the SIS.
- Material Data Requirements
 - Data shall be provided supporting the basis of material selection and compatibility with the environment. Combined effect of temperature and radiation on material performance shall be considered.
 - Process and traceability material data demonstrating that the material of the tested SIS is equivalent to materials designated in the manufacturing specification.
- Limits of Failure Definition
 - The SIS qualification is considered failed if any of the following conditions occur.
 - a) failure to meet any of the functional parameters (e.g., damping resistance, drag force, spring rate, etc.) specified for the SIS in the Qualification Specification, while being loaded to its specified load ratings for any loading condition.
 - b) failure to meet any of the functional parameters during/after being subjected to the environmental conditions specified in the Qualification Specification.
 - c) failure to meet any of the special testing requirements of the Qualification Specification.

- d) failure to pass a post-test examination and analysis after all testing and exposure to the environmental conditions specified in the Qualification Specification.

- Post-test Examination and Analysis

- The tested SIS shall be disassembled, examined and subjected to a post-test analysis documented in the qualification report with the following information.
 - a) Identification of SIS
 - b) The last conducted test in the test sequence
 - c) Post-test condition analysis of SIS
 - d) Summary, conclusions and recommendations
 - e) Approval signature and date
 - f) Disposition of the SIS

7.7.2.2 Candidate Qualification

Candidate SIS for future plant applications that are identical to the parent SIS (same manufacturer, type, size, rating, etc.) are qualified by providing an Application Report in accordance with ASME QME-1 QDR-7320 based on the parent Qualification Report.

Candidate SIS not identical in construction to the parent SIS may be qualified by extension through appropriate analysis and/or testing. The procedure for candidate SIS qualification requires a high degree of similarity to ensure that the mechanical strength, stiffness, and critical design tolerances of the candidate SIS favorably compare with the qualified parent SIS. The basis of addressing differences relies on test-verified analysis in accordance with ASME QME-1 QDR-6300. Similarity requirements, allowances for differences and the procedure requirements for test-verified analysis are provided in QDR-6320 and 6330 and will be adhered to for all candidate SIS qualification that are not identical to the parent SIS. Extension of the qualification requires that all requirements of the construction code ASME.BPVC.III.1 Subsection NF are met. In addition, the following are considered in establishing similarity of the design.

- Design/Configuration: Candidate SIS parts shall be similar in design and configuration with the principal difference being the overall size and/or weight.
- Materials: Material differences of construction shall be addressed and demonstrated to be acceptable by adjusting material properties and considering functional performance capabilities of the differing materials.
- Dimensions/Tolerances: Differences of physical dimensions and tolerances shall be reconciled for the candidate SIS.
- Surface finish: Surface finish differences shall be considered in addressing the functional parameters.
- Fabrication/Assembly Method: Differences in construction methods shall be considered.

- Coatings/Plating: Differences in coatings/plating shall be reconciled.
- Production Testing: Differences in production testing methods shall be reconciled.

7.7.3 Qualification Documentation Requirements

Qualification documentation is required to verify that the SIS is qualified to perform its intended functions within the environmental constraints specified. Qualification demonstrates that the service requirements are met by testing and/or analysis performed under the qualification program. Qualification documentation consists of the following:

- a) Qualification Plan (QDR-7200) – translates the qualification specification requirements into a step-by-step qualification process.
- b) Qualification Report (QDR-7310) – documents the qualification of the parent SIS in compliance with ASME QME-1 QDR. The qualification report shall be certified by a Registered Professional Engineer in accordance with QR-8620.
- c) Application Report (QDR-7320) – document the qualification of a candidate SIS for a specific application in a nuclear facility. The application report shall be certified by a Registered Professional Engineer in accordance with QR-8630.

Additional requirements with respect to the content of qualification documentation are in QDR-7000 and shall be applicable to the SIS.

7.8 Reactor Seismic Isolation System Lifetime Management

The Reliability and Integrity Management (RIM) Program provides direction for assuring the reliability and integrity of passive components whose failure could adversely affect plant safety and reliability. The RIM Program is outlined in the ASME.BPVC.XI.2, “Requirements for Reliability and Integrity Management (RIM) Programs for Nuclear Power Plants” [4] as endorsed by RG 1.246 [25]. The RIM Program involves design interaction, performance monitoring, inspections, tests, maintenance, replacements, etc., as strategies to ensure the SSCs achieve an acceptable level of reliability to support PRA/SPRA of the plant.

The RIM program addresses the lifecycle of each component within the scope of the program. The RIM program ensures that each component performs as designed and have a reliability consistent with the assumptions used to develop the PRA for the plant.

The RIM program includes two expert panels: the RIM expert panel (RIMEP) and the monitoring and non-destructive examination expert panel (MANDEEP). The RIMEP provides the technical oversight and direction of the risk-informed aspects of the RIM Program development which consists of the following elements:

- Establishing the scope of the program
- Conducting a degradation mechanism assessment (DMA) for each component in the scope of the RIM Program

- Allocating Reliability Targets from the PRA/SPRA for each component within the scope of the program
- Establishing RIM strategies for each component within the scope of the program
- Implementing the RIM Program
- Uncertainty evaluation
- Monitoring program performance
- Updating the program

The MANDEEP develops procedures for monitoring and non-destructive examination (MANDE), including procedure, personnel, and equipment qualification requirements; developing new technologies for examination; and establishing acceptance criteria for MANDE indications identified. The overall RIM process over the life of the SSCs is illustrated in Figure 7-10.

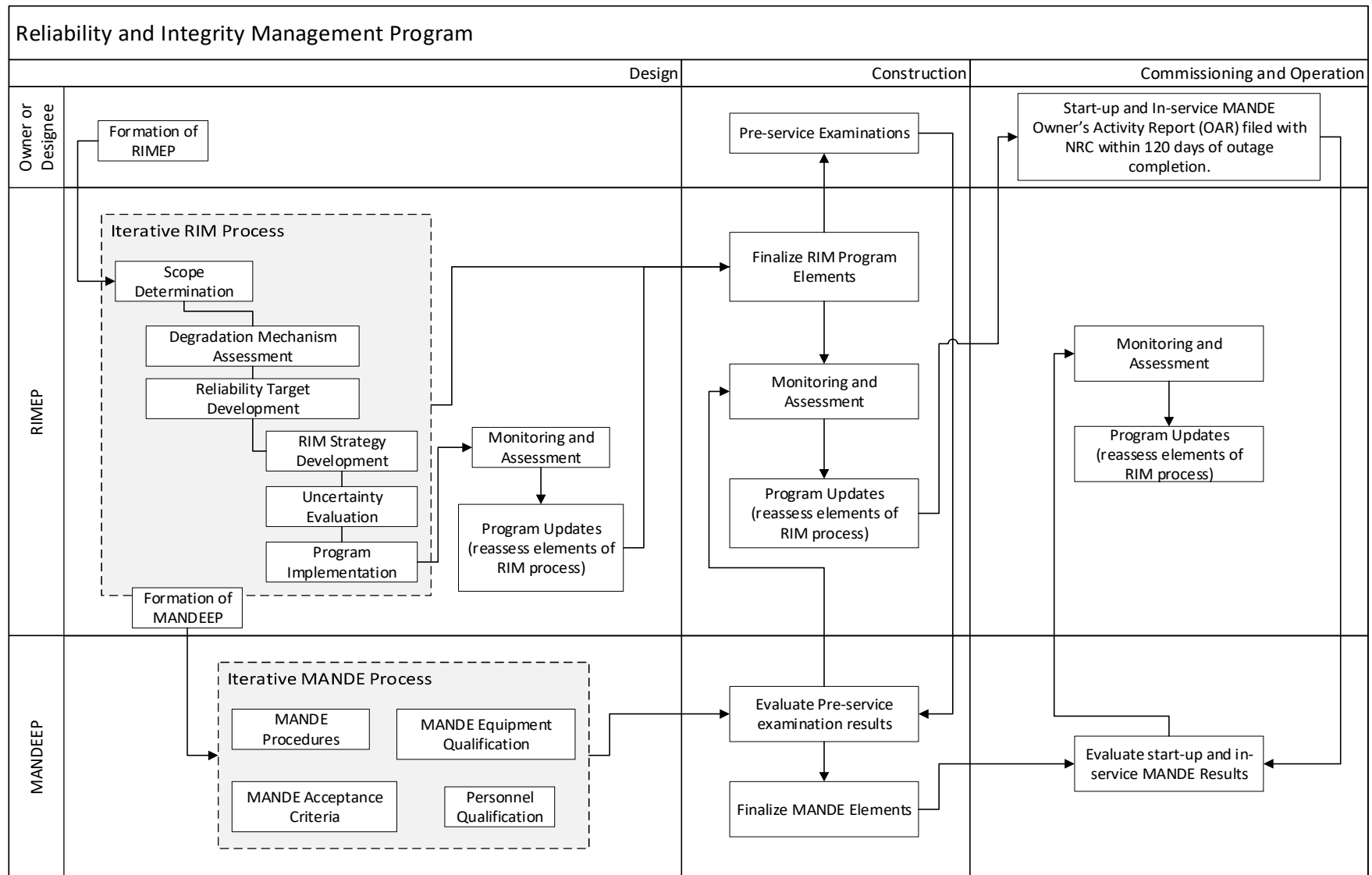


Figure 7-10. Reliability and Integrity Management Program Implementation

7.8.1 Reliability and Integrity Management Program Elements

RIM Scope:

The scope of the RIM Program is determined by the RIMEP. ASME.BPVC.XI.2, RIM-2.2, "RIM Program Scope and Definition", states that the scope shall include SSCs whose failure could adversely affect plant safety and reliability. The reactor SIS provides passive support and attenuation of seismic loads to the reactor and its classification is safety-related and seismic risk significant. In accordance with the scope definition in ASME.BPVC.XI.2 the SIS is included within the scope of the RIM program.

Degradation Mechanism Assessment:

A degradation mechanism assessment (DMA) for SSCs within the scope of the RIM Program shall be prepared in accordance with ASME.BPVC.XI.2, RIM-2.3. Mandatory Appendix VII, "Supplements for Types of Nuclear Plants," of ASME.BPVC.XI.2 is typically used to complete this assessment. The Section of Appendix VII that addresses liquid metal-type reactors is in the course of preparation and it will focus on the degradations for components subjected to the sodium environment.

The RIMEP will develop the DMA for the reactor SIS. The DMA considers the following conditions:

- Design characteristics, including material, component type, and other attributes related to the system configuration.
- Fabrication practices, including welding and heat treatment.
- Operating and transient conditions, including temperatures, pressures, dynamic loads and service environment (humidity, radiation, etc.)
- Plant-specific, industry-wide service experience and research experience
- Results of preservice, inservice, and augmented examinations and the presence and impact of prior repairs in the system (may be provided by vendor operating experience)
- Recommendations by SSC vendors for examination, maintenance, repair, and replacement.

Once the DMA is completed for the SIS, the MANDEEP will determine what MANDE methods are applied to ensure the SSC will function with an acceptable level of reliability.

Reliability Target Allocation:

To perform the reliability target allocation for the SIS, the PRA/SPRA is reviewed in terms of scope, level of detail, and technical adequacy for use with RIM and the development of Reliability Targets. ASME.BPVC.XI.2, RIM 2.4.3, "Scope, Level of Detail, and Technical Adequacy of the PRA", outlines the scope of the PRA/SPRA that is used to allocate Reliability Targets.

- The plant operating states relevant to the plant level risk and reliability goals and SSC-level Reliability Targets.
- A full set of initiating events including internal events and events associated with external plant hazards.

- Event sequence development that is sufficient to support the quantification of mechanistic source terms and offsite radiological consequences consistent with applicable regulatory limits on the frequencies and consequences of accident scenarios.

All plant operating modes are to be addressed; however, it is not required to have a full-scope PRA as outlined above (qualitative treatment of other risk information related to missing modes and hazard groups may be sufficient if it can be demonstrated that those risk contributions would not affect the Reliability Targets or other aspects of the RIM Program). The PRA should meet the requirements of ASME/ANS RA-S-1.4-2021, Probabilistic Risk Assessment Standard for Advanced Non-Light Water Reactor Nuclear Power Plants [36], endorsed in Trial RG 1.247 [37], to the extent necessary to support RIM Program development.

RIM Strategy Determination:

Once the DMA for the SIS is complete and the reliability target is established, a RIM strategy is developed to address the degradation mechanisms applicable to the SIS such that the SIS will be able to function and achieve the reliability established for the SIS. The RIM strategies balance design margin and MANDE methods. Where design margin is low, increased MANDE would be expected. Where design margin is high, a lesser amount of MANDE methods would be needed. The RIM strategies shall account for all the factors that contribute to reliability, including but not necessarily limited to:

- Design strategies, including material selection
- Fabrication procedures
- Operating practices
- Preservice and inservice examinations
- Testing
- MANDE
- Maintenance, repair, and replacement practices

RIM strategies may include the use of monitoring, surveillance and/or inspections (NDE). As an example, the SIS viscous fluid may utilize surveillance specimens to monitor fluid viscosity, subjected to environmental stressors such as temperature and radiation. The samples may be retrieved periodically and tested to determine the change in viscosity. If the viscosity degrades below a certain threshold, replacement of the damper fluid or the IDU may be required. Surveillance samples are placed such that they provide an early indication (leading environmental condition) of on-going degradation allowing for preemptive actions to remedy the degraded condition. Other degradation mechanisms of the SIS such as corrosion, or relaxation may be addressed by visual inspections. The benefit of the RIM strategies is that they are developed for each component systematically as opposed to using generic prescriptive NDE.

Uncertainty Evaluation:

In accordance with ASME.BPVC.XI.2 RIM-2.6 uncertainties shall be accounted for in the development of RIM strategies. Specifically, the RIMEP shall identify additional RIM strategies over and above those determined in the normal development of strategies that are necessary to provide additional assurance

that the reliability targets will be achieved and maintained during the SIS service lifetime in order to address uncertainties in predicting SIS reliability performance. These additional RIM strategies that are established to address uncertainty shall be documented in accordance with all the other RIM strategies. These strategies should clearly identify that they are intended to address uncertainty.

ASME.BPVC.XI.2, RIM-7, Glossary, has two definitions of uncertainty, one as used in PRA, and one as used in MANDE. Uncertainty as used in PRA is a representation of the confidence in the state of knowledge about the parameter values and models used in constructing the PRA. The uncertainties in PRA may be characterized by testing and/or operating experience and may utilize statistical inference analysis or similar. Uncertainty as used in MANDE is a quantification representing the variability associated with monitoring and non-destructive examination (MANDE) data and includes many technique and application specific parameters such as the minimum detection capability, sizing accuracy, resolution tolerance, repeatability, consistency, etc.

Program Implementation:

Once the RIM Program scope is established, the degradation mechanism assessment is completed, the Reliability Targets established and the RIM strategies are established, the program will shift towards the activities of the MANDEEP. While the MANDEEP will function in parallel with the RIMEP, the MANDEEP activities flow from the direction of the RIMEP. Once the RIMEP establishes the RIM strategies, the MANDEEP will then commence work on MANDE procedure development and procedure, personnel, and equipment qualification as needed to implement the RIM strategies. The MANDEEP will also establish the pre-service inspection activities needed for the RIM Program.

The schedule of pre-service MANDE and inservice MANDE will need to be included in the RIM Program document. This will provide the timing for examinations just prior to start-up activities and during operation of the plant. The schedule of examinations may change over time as the program is adjusted due to program updates based on the results of inspections and industry experience.

After each outage during which RIM Program inspections are performed, an Owner's Activity Report (OAR) form will need to be filled out and sent to the NRC within 120 days (RG 1.246 [25]) of the outage completion date. The OAR is a record of the inspections performed in accordance with the RIM Program and results of the inspections, documentation of any repair/replacements that were made, etc. If there were analytical evaluations performed to accept any examination results that exceeded the initial acceptance criteria for a flaw, these are also to be submitted to the NRC within 120 days of the end of the outage completion date.

RIM Program Changes:

During the course of development and implementation of the RIM program changes may occur due to a variety of factors such as design maturity and changes, availability of improved MANDE methods, new operating experience, etc. In these situations, the RIM Strategy will need to be re-evaluated and alternative strategies developed to meet the reliability target for the SSC.

Certain changes are required to be reviewed by the NRC. Other changes do not require review and approval, but only notification of a review. These are outlined in RG 1.246 [25] position 4. Changes which require NRC review and approval are:

- Changes to methodologies for establishing Reliability Targets and for demonstrating RIM strategies will be of satisfying Reliability Targets.

- Alternatives to the ASME.BPVC.XI.2 as endorsed in RG 1.246.
- RIM Program changes involving alternate examination methods developed under ASME.BPVC.XI.2, Appendix A.
- Flaw evaluation criteria developed for temperatures that exceed the temperature ranges of ASME BPVC.III.1.
- Changes to the schedule for submitting OAR forms.

For any other RIM Program changes, the NRC should be notified of the changes, but NRC review and approval is not required. These notifications should be provided prior to the next scheduled refueling outage or within 3 years of making the change, whichever is less.

Monitoring and Assessment:

Once the bulk of the work of establishing the scope of the RIM Program, DMA, Reliability Target allocation, and RIM Strategies are identified the program transitions into the implementation phase. As inspections are completed, the data obtained from the inspections is evaluated for acceptability. The initial evaluation is done when the inspection is completed. The results are directly compared to acceptance criteria. If acceptance criteria are not met, corrective actions are taken. Corrective actions are executed in accordance with the ASME BPVC.XI.2 direction. Supplemental examinations and the extent of the condition may result in additional component inspections.

Trending of results is also part of the monitoring and assessment phase of the program. The RIMEP is tasked with monitoring and assessing the RIM Program and will need to evaluate data over all the inspections and compare to the baseline established during the PSI. Evaluations are to be done to ensure the equipment will remain in an operable state until at least the next scheduled inspection.

Program Updates:

RIM Program updates are required periodically by ASME.BPVC.XI.2, however, the periodicity of update is generally on an as-needed basis, or it is to be updated no later than the end of each established inspection interval. ASME.BPVC.XI.2, RIM-2.8, discusses re-evaluation of the RIM program for when updates may be needed, such as new information becoming available. Changes to the SIS such as material changes, new configurations, stress changes resulting from design changes, or plant risk changes from PRA/SPRA updates could warrant a RIM Program update. Changes to plant procedures that result in different operating parameters, system line-ups, equipment and operating modes may result in different degradation mechanisms or impact the capability of MANDE. Changes in SIS performance, indicating a change in SIS reliability may warrant RIM Program updates. MANDE results that indicate service-related degradation may warrant a RIM Program update. Industry or research experience, including SIS failure or reliability data changes or new degradation mechanisms may warrant a RIM Program update. If no new information becomes available, the minimum frequency of RIM Program updates is to be at each inspection interval of the SIS. The inspection interval is to be established by the RIMEP and shall not exceed 12 years. The duration of each inspection interval should be documented in the RIM Program document.

8 CONCLUSIONS

The report herein outlines the background information, technical basis, and regulatory evaluation for developing the reactor seismic isolation system. Design specific applicability of the regulatory and industry guidance to the TerraPower Natrium Plant reactor seismic isolation is summarized based on research performed on publicly available documents for passive three-dimensional equipment SIS.

The construction and qualification methodology presents the flow-down of quality, standards, records, licensing, design, fabrication, inspection, monitoring, operations, and maintenance requirements for the reactor SIS. The framework provides a comprehensive and complete set of requirements through the entire life-cycle of the SIS that supports the fundamental safety of the plant stemming from decades of operating experience. The methodology provided presents a risk-informed, performance-based design approach for seismic isolation that is consistent with the NRC endorsed guidance of the licensing modernization project.

The methodology identifies the applicable codes and standards when the three-dimensional SIS is used for supporting the reactor for licensing basis events. Consistent with the risk-informed performance-based design approach, the reactor SIS is safety-related and seismic risk significant. Reactor support components have been licensed using the ASME.BPVC.III code for the operating fleet. Consistent with the ASME.BPVC jurisdictional boundaries and licensing precedence the Natrium reactor SIS is an ASME.BPVC.III standard support.

Furthermore, the reactor SIS is a mechanical component qualified in accordance with ASME QME-1. The SIS consists of separate ISUs and IDUs which are qualified with consideration of the specific characteristics of each. The RIM program provides direction for assuring the reliability and integrity of the passive seismic isolation system whose failure could adversely affect plant safety and reliability in accordance with ASME.BPVC.XI.2. The RIM Program involves design interaction, performance monitoring, inspection, test, maintenance, replacement, surveillance, as strategies to ensure the SIS achieves an acceptable level of reliability to support probabilistic risk assessment of the plant over its lifetime.

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10 APPENDICES

Appendix A. Seismic Isolation Technologies and Applications

10.1 Seismic Isolation Technology Overview

The general requirements of ASCE/SEI 4-16, "Seismic Analysis of Safety-Related Nuclear Structures," ASCE 4-16, Chapter 12 [33] pertaining to SIS of safety related (SR) structures including requirements for analysis, construction as well as methods of analysis, and peer review/testing requirements are similar to those considerations and recommendations discussed in NUREG/CR-7253 [6]. Per ASCE 4-16, the following isolators are the only types assessed for use of SR nuclear structures. (1) low-damping (natural) rubber (LDR), (2) lead-rubber (natural) (LR), and (3) Friction Pendulum (FP) sliding isolators (shown in Figure 10-1). In accordance with ASCE 4-16, each has been tested extensively, can be modeled for nonlinear response-history analysis, and has been deployed in mission-critical structures. Some key characteristics of the three seismic isolation technologies are as follows:

- LDR bearings are composed of alternating layers of natural rubber and steel and can be modeled as viscoelastic components. The shear modulus of the rubber ranges between 60 psi and 120 psi. The equivalent viscous damping ratio is between 2% and 4% of critical damping.
- LR bearings are constructed similarly to LDR bearings but include a central lead core to dissipate earthquake-induced energy.
- FP bearings consists of an inner slide that slides along two (2) concave sliding surfaces with the restoring force provided by the gravity weight of the structure.

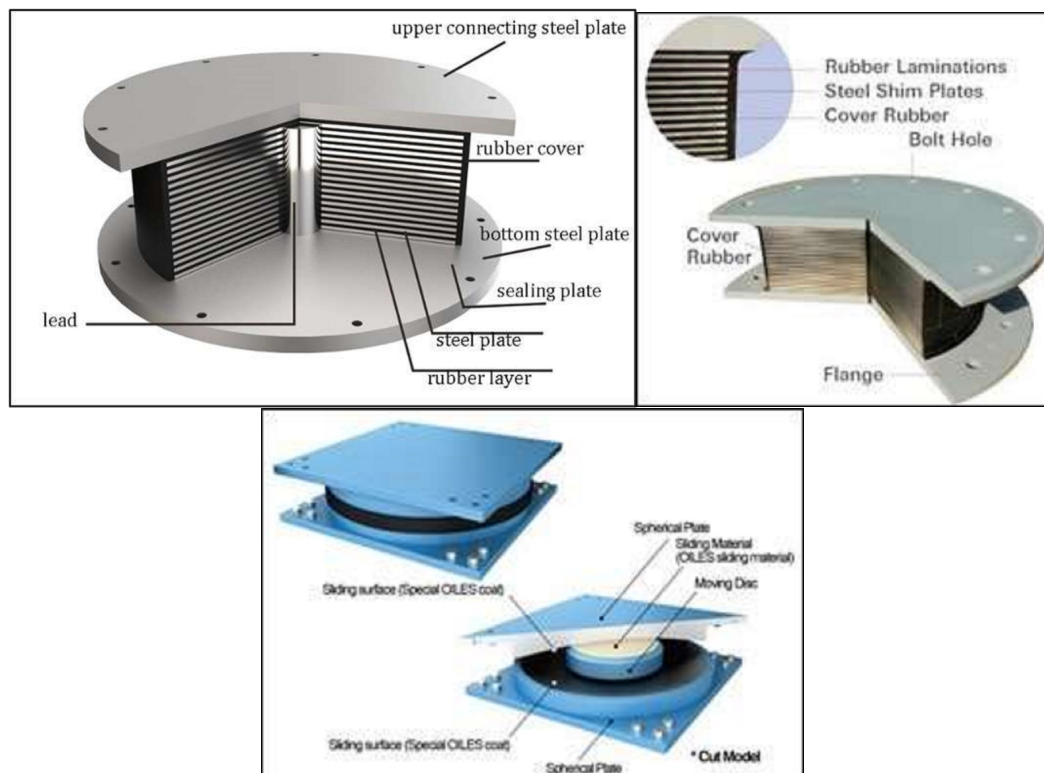


Figure 10-1: Seismic Isolation technologies addressed in regulations; a) low-damping rubber (LDR); b) lead rubber (LR); c) friction pendulum (FP) sliding.

The SIS technologies addressed by the currently available regulatory guides [6], [8], and [9] as well as ASCE 4-16, are only effective in the horizontal direction and generally require to be modeled with non-linear constitutive models as recommended by the reports. In contrast, many mission critical infrastructure in the United States as well as SR SSCs in NPPs around the world already benefit from three-dimensional SIS technology. One such technology consists of a plurality of helical spring and viscoelastic dampers (referred to as three-dimensional SIS). In Section A.1.3 of IAEA-TECDOC-1905 [38] published by the International Atomic Energy Agency (IAEA) on the topic of seismic isolation, helical spring elements are noted as the simplest rigidity element that can be used to construct SIS sub-assemblies. The report also notes that a relatively simple linear model can be used to assess the mechanical response of a structure mounted on three-dimensional SIS.

An example of three-dimensional SIS is shown in Figure 10-2 courtesy of GERB Vibration Control Systems of Germany, the manufacturer of these devices. The technology is based on helical springs which provide flexibility of similar order in all three directions and approximately velocity proportional viscoelastic dampers, also effective in all directions. It should be noted that GERB (established in 1908) is the most prominent vendor supplying three-dimensional SIS technology, and much of the publicly available information on the performance of three-dimensional SIS has been published by GERB. However, there are additional vendors that manufacture similar three-dimensional SIS devices based on helical springs and viscoelastic dampers, and the characteristics discussed herein and approach for seismic qualification for use in NPPs in the United States are expected to be valid regardless of the manufacturer.

Three-dimensional SIS technology such as shown in Figure 10-2 utilizes only passive components. The three-dimensional SIS is typically comprised of multiple assemblies of springs and dampers which are installed in parallel for redundancy. A spring unit and an integrated spring-damper unit is shown in Figure 10-2 (a) and (b), respectively. The internal design of the dampers is shown in Figure 10-3 [12] and consists of the damper housing, a non-pressurized fluid container, filled with viscous damper fluid and piston immersed in the fluid. The damper housing and the piston are attached to opposite end plates of the damper. As a results of relative movement of the piston to the housing, forces emanating from the motion of the viscous fluid provide effective load transfer and damping forces between the supporting and supported SSC.

The dampers are passive and do not require power or control signal to operate. Unlike other types of seismic restraint technologies, there are no seals separating pressurized chambers and/or valves that could fail. There are no adjustable orifices to set the operational range of the damper that needs to be calibrated and adjusted. In addition, unlike the base isolation SIS discussed in [6] [8], and [9], the dampers are only load bearing during seismic shaking. When at rest, they provide relatively easy access to the damper fluid which can be inspected, sampled, and serviced, and without a need for jacking the supported structure. Depending on the application, the dampers work with different viscous fluids. In applications where environmental conditions include radiation, the resistance of the damper fluid is an important factor in determining the appropriate chemical composition. Three types of damping fluids have been irradiated and the damper characteristic tested [28] up to 200 kGy gamma-radiation levels. Tests have demonstrated that the bituminous and polybutene based fluids remain functional to this level of radiation while the silicone oil-based fluid stiffens and its damping decreases. Radiation zones in nuclear facilities where the dampers are typically located usually remain well below these radiation levels.

The use of helical coil springs and viscoelastic dampers that provide approximately velocity proportional damping force means that the dynamic response to earthquake shaking can be modeled efficiently and with minimal uncertainty for design basis ground motions. Tests on seismic isolation units demonstrate good correlation between measurement and numerical models using ideal springs and dampers. One such model is the Double Maxwell-Model proposed in [12] and [39]. The relevant constitutive (or mathematical) model is linear, and available by default in most finite element software used in NPP design.

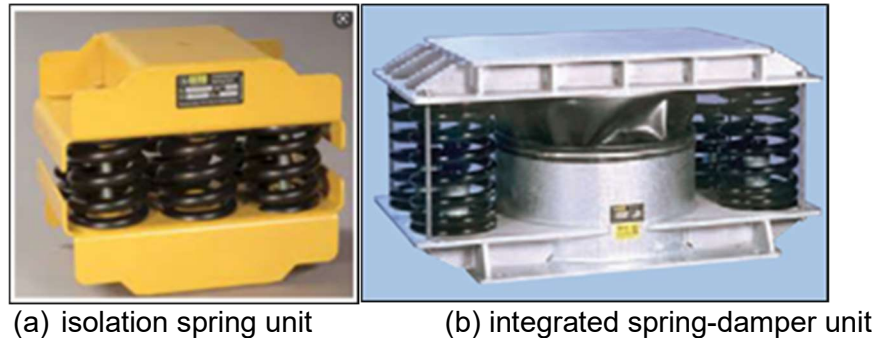


Figure 10-2: Three-dimensional Seismic isolation system examples. Image courtesy of GERB Vibration Control Systems of Germany.

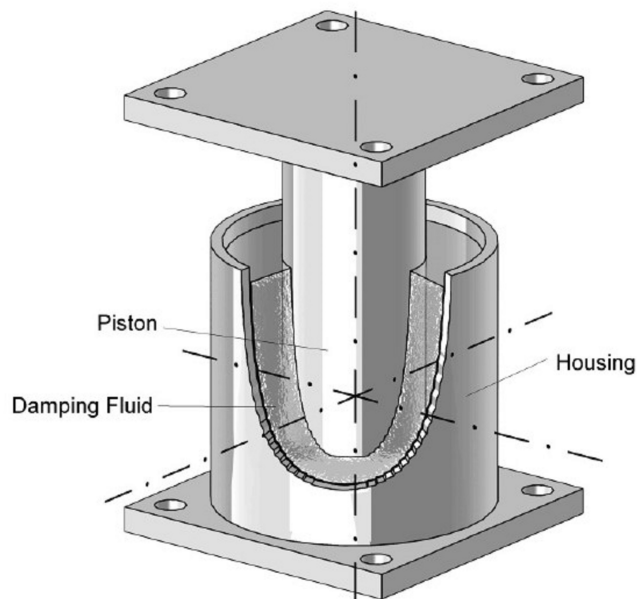


Figure 10-3: Elements of dampers. Image courtesy of GERB Vibration Control Systems of Germany.

10.2 Seismic Isolation Applications

There are six Pressurized Water Reactor (PWR) NPPs that use seismic isolation, all for superstructure horizontal isolation. All six plants were constructed in the 1980s. Four reactors are located at Cruas-Meyssse NPP in France and two are located at Koeberg NPP in South Africa. Licensee application of the PRISM design planned to use a horizontal SIS system using high-damping, steel-laminated, elastomeric bearing. The NPP structure basemat is isolated from the foundation structure as shown in Figure 5-2 and Figure 10-4. The seismic isolation units are installed on concrete piers attached to the foundation structure which creates a seismic gap (moat) between the basemat and the foundation structure. The foundation structure also has a stop wall around the perimeter to prevent excessive movement of the isolated structure. The Isolators in these NPPs use neoprene elastomer bearings [6].

Due to the use of elastomeric materials and exposure to harsh environmental conditions (temperature fluctuations, and elements of nature) LDR and LR SIS require regular maintenance. The synthetic rubber (a neoprene) used in the French isolators, has stiffened significantly (37%) over time, changing the properties of the SIS. The isolator properties are monitored and changed out as necessary. The bimetallic interface used in the South African isolators is no longer considered viable for use in seismic bearings because the mechanical properties of such interfaces can change substantially with time.

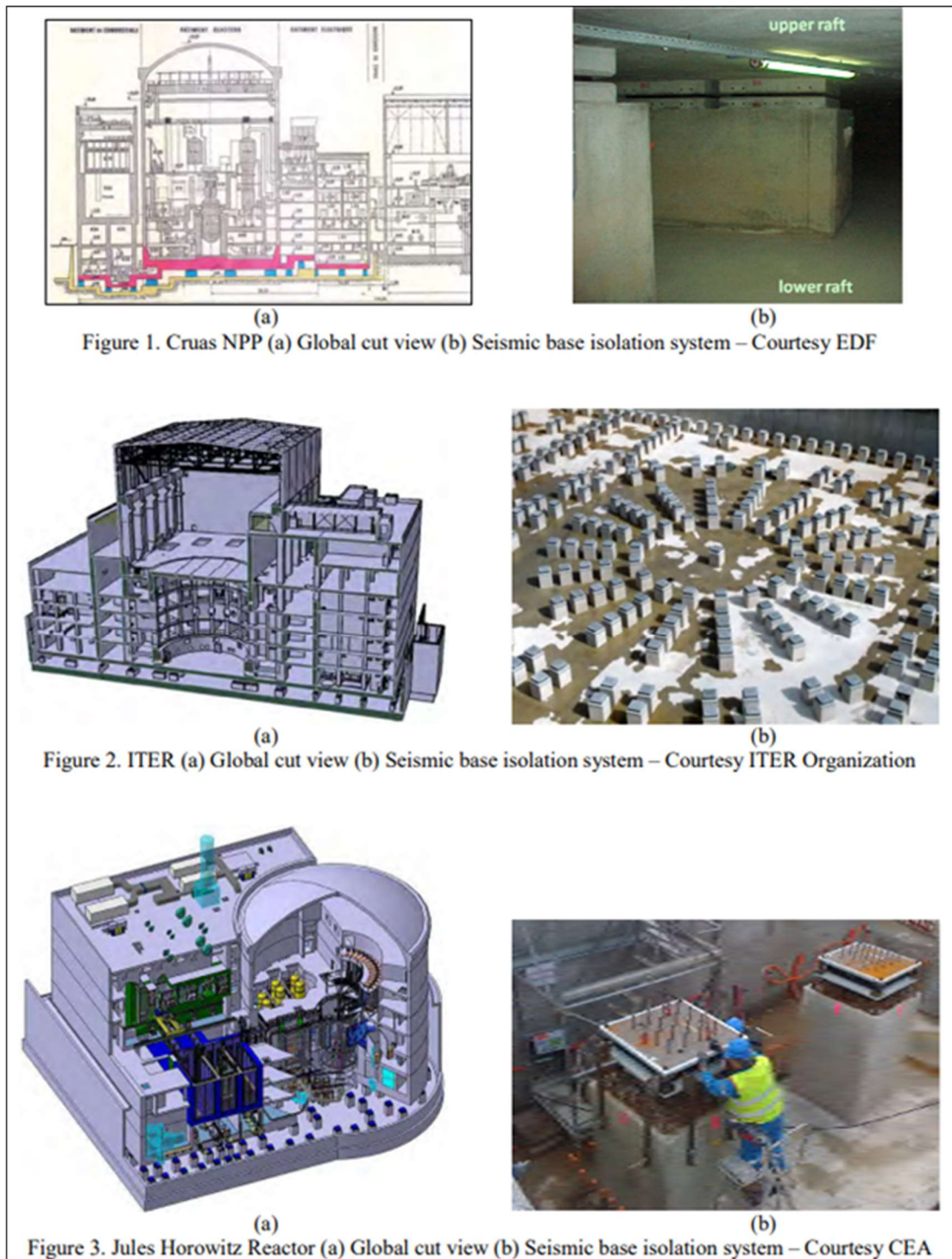


Figure 10-4: Seismic isolation examples of nuclear facilities

Three-dimensional vibration control and seismic isolation of equipment in the power industry has numerous reference installations including nuclear facilities. GERB has provided solutions for various equipment seismic isolation as illustrated in Figure 10-5 [40]. A list of reference piping work SIS installed in NPPs is provided in Table 10-1. Another group of major power plant applications include SIS of

turbine foundations as shown in the reference project list in Table 10-2. Other major reference installations in overseas and US nuclear facilities include:

- Vogtle AP1000 plants 3 and 4 turbine decks.
- Emergency diesel generators and spent fuel pool in Gösgen, Switzerland.
- Main Control Room in Olkiluoto, Finland.
- Waterford 3 piping system.
- Water-water energetic reactor (VVER) 440/213 primary loop in Mochovce NPP in Slovakia [41].
- Safety-related hot pipelines and other components including the steam generators and pressurizer in V1 in Jaslovske Bohunice VVER 440/230 type reactors [41].
- Main reactor cooling pump and steam generator seismic isolation of the VVER 1000 NPP in Temelin, Czech Republic [41].

In addition, the technology has been installed in thousands of mission-critical, commercial and infrastructure projects such as hospitals, bridges, opera houses and large commercial buildings around the world. Suppliers of the technology (such as GERB) report decades of operating experience and extremely low probability of failure. One of the earliest installations of such system in a NPP was in 1968 at the German Stade NPP [27]. After 35 years in operation, the plant was decommissioned and one of the turbine generator deck isolators was extracted and retested. Visual inspection of the springs only indicated minor paint spalling, but no corrosion of the spring elements was evident. The spring critical characteristics (spring rate, deflections and unloaded tolerances) were tested in a laboratory which indicated spring performance remained within the original specifications after 35 years of bearing load and exposed to NPP environmental conditions.

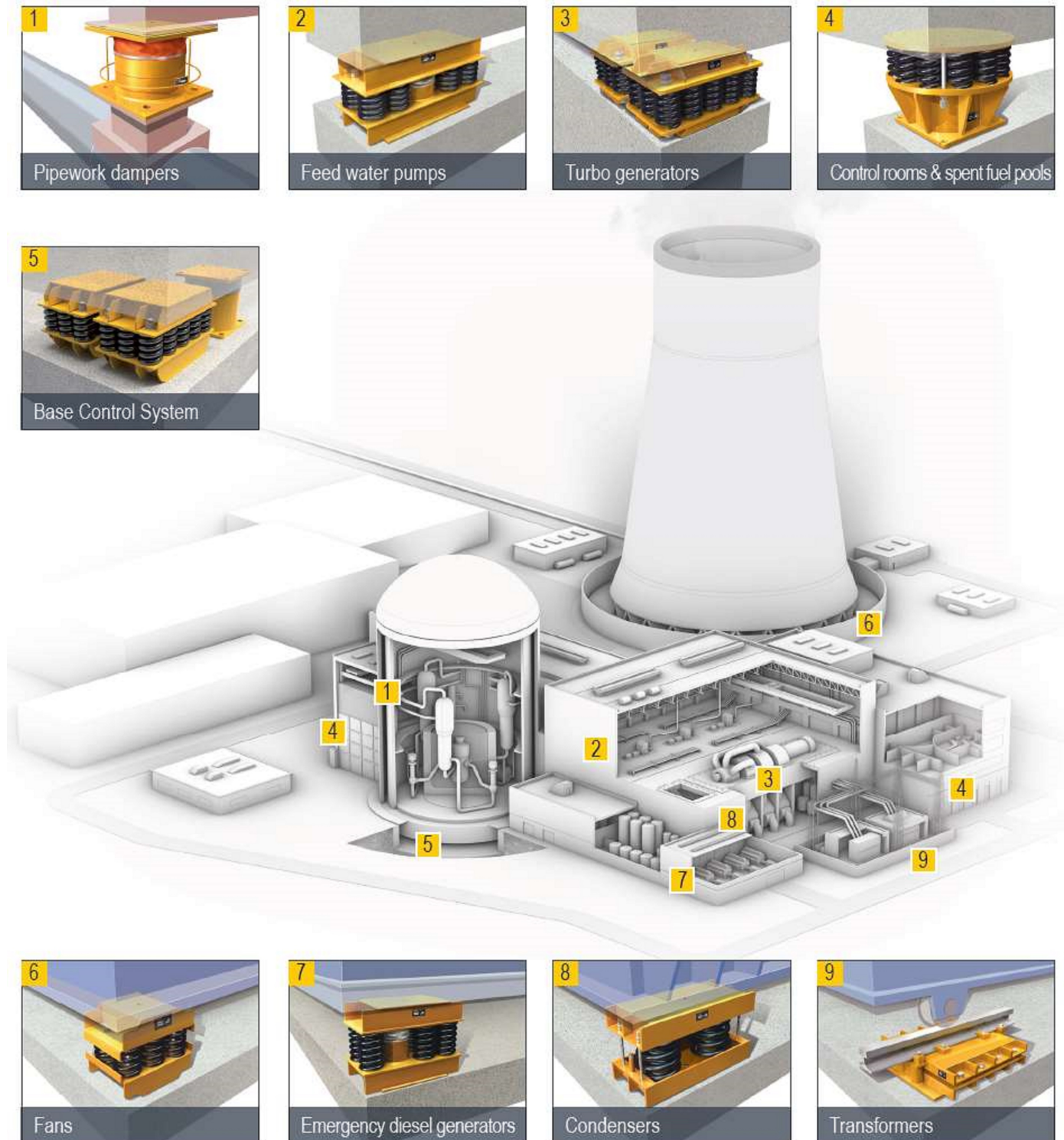
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Figure 10-5. GERB seismic isolation systems in nuclear power plants and small modular reactors

Table 10-1. GERB Pipework Damping System for Nuclear Power Plants (1998-2022)

Nuclear Power Plant	Project Year	Country
Armynskaya NPP	2022	Armenia
Akkuyu NPP	2022	Turkey
Novovoronezhskaya NPP	2022	Russia
Arkansas NPP	2022	USA
Kudankulam NPP	2022	India
Armenian NPP	2021	Armenia
Akkuyu NPP	2021	Turkey
Kurskaya NPP	2021	Russia
Belorusskaya NPP	2021	Belarus
Flamanville 3 NPP	2021	France
Olkiluoto 3 NPP	2021	Germany
Ruppur NPP	2020	Russia
LAES II NPP	2020	Russia
Belorusskaya NPP	2020	Belarus
OKG NPP	2020	Sweden
Oskarshamn III NPP	2019	Sweden
Fortum NPP	2019	Finland
LAES II NPP	2019	Russia
KudanKulam NPP	2018	Russia
Olkiluoto III NPP	2018	France
Shimane II NPP	2018	Japan
Rivne NPP	2018	Czech Republic
Mochovce 1+2 NPP	2018	Slovakia
BELAES II NPP	2017	Ukraine
Olkiluoto III NPP	2017	Austria
Waterford 3 NPP	2017	USA
NVAES II NPP	2016	Russia
Oskarshamn I NPP	2016	Sweden
Tianwan III & IV NPP	2015	China
Oskarshamn 3 NPP	2015	Sweden
LAES II NPP	2015	Russia
KW Marl NPP	2015	Austria
AKRON Novgorod NPP	2015	Russia
Belorusskaja NPP	2015	Russia
Novovoroneshkaja II NPP	2015	Russia
LAES II NPP	2015	Russia
Leningradskaja II NPP	2015	Russia
Chugoku NPP	2014	Japan
Novovoroneshkaja NPP	2014	Russia
Novovoroneshkaja II NPP	2014	Russia
Belojarskaja NPP	2014	Russia
Chugoku NPP	2014	Japan
Novovoroneshkaja II NPP	2014	Russia
Novovoroneshkaja I NPP	2014	Russia
Chugoku NPP	2014	Czech Republic
Belojarskaja NPP	2013	Russia
Belojarskaja NPP	2013	Russia

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Nuclear Power Plant	Project Year	Country
Novovoroneshkaja NPP	2013	Ukraine
KKW Saporoshje Ukraine NPP	2013	Germany
Krasnodarskaja NPP	2013	Russia
Novovoroneshkaja NPP	2013	Ukraine
Mochovce NPP	2013	Czech Republic
PAKS NPP	2012	Germany
Mochovce NPP	2012	Czech Republic
Mezamor NPP	2012	Armenia
Cooper NPP	2012	USA
Temelin NPP	2012	Czech Republic
PAKS NPP	2012	Hungary
Temelin NPP	2011	Czech Republic
Mochovce NPP	2011	Slovakia
Kurskaja NPP	2010	Russia
Olkiluoto NPP	2009	Germany
Paks II NPP	2009	Hungary
Olkiluoto NPP	2009	Germany
Paks II NPP	2009	Hungary
Shearon's Harris NPP	2009	USA
Paks IV NPP	2009	Hungary
Paks I NPP	2009	Hungary
Brunsbüttel NPP	2009	Germany
Mezamor NPP	2008	Czech Republic
Isar NPP	2008	Germany
Olkiluoto NPP	2008	Germany
Oskarshamn NPP	2008	Sweden
Paks NPP	2008	Hungary
Oskarshamn NPP	2007	Sweden
Tianwan NPP	2007	China
Krsko NPP	2007	Slovenia
Gösgen NPP	2007	Germany
Paks NPP	2006	Hungary
Temelin NPP	2006	Czech Republic
Bohunice NPP	2006	Slovakia
Paks NPP	2006	Hungary
Cernavoda II NPP	2005	Romania
Bohunice NPP	2005	Slovakia
Angra NPP	2005	Germany
Temelin NPP	2004	Czech Republic
Oskarshamn NPP	2004	Sweden
Grafenrheinfeld NPP	2004	Germany
Brunsbüttel NPP	2003	Germany
Tianvan NPP	2002	Rusia
Loviisa NPP	2002	Finland
Forsmark NPP	2002	Sweden
Temelin NPP	2002	Czech Republic
Temelin NPP	2001	Czech Republic
Bohunice NPP	2001	Slovenia

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Nuclear Power Plant	Project Year	Country
Brunsbüttel NPP	2001	Germany
Loviisa NPP	2001	Finland
Brunsbüttel NPP	2000	Germany
Paks III - IV, NPP	2000	Hungary
Angra NPP	2000	Germany
Cernavoda NPP	2000	Romania
Angra NPP	1999	Germany
Loviisa NPP	1999	Finland
Mochovce NPP	1999	Slovakia
Paks I + II NPP	1998	Hungary

Table 10-2. GERB Pipework Damping System for Nuclear Power Plants (1998-2022)

Country	Power Plant	Manufacturer	Capacity (MW)	Delivery Date
Argentina	Atucha	KWU	745	1981
Australia	Northern Power Station	Mitsubishi	2 x 275	1979
	Loy Yang 'A'	KWU	3 x 500	1980
	Loy Yang 'A'	BBC	500	1980
	Loy Yang 'B'	Hitachi	500	1988
	Tarong	Hitachi	4 x 350	1983
	Callide	Hitachi	2 x 350	1983
	Collie	ABB Baden	300	1983
	Stanwell	Hitachi	4 x 350	1984
Austria	Tullnerfeld	KWU	730	1976
	Voitsberg	MAN	300	
	Dürnrohr	KWU	405	1982
	Riedersbach	Franco Tosi	160	1982
	Mellach Süd	BBC Baden	275	
	Liebenfels	MAN		2017
Bangladesh	Ashugong	BBC	2 x 150	
	Ruppur		1200	2018
Belgium	Drogenbos	Alsthom	172	1993
	Seraing	Alsthom	172	1994
	Brügge	GEC Alsthom	172	1996
Brazil	Angra	KWU	2 x 1300	1979
	TKS CSA Rio de Janeiro	Alstom Baden		2007
China	Beijing	ABB	2 x 300	1997/8
	Hefei	ABB	2 x 350	1993
	Tianwan 1 + 2	LMZ	2 x 1000	2001/2002
	Dabieshan	Alstom (Beizhong)	2 x 600	2007
	Pingliang	Alstom (Beizhong)	2 x 600	2008
	Ling'ao	Alstom (DongFang)	2 x 1000	2008
	Fangjiashan	Alstom (DongFang)	2 x 1000	2009/10
	Hongyanhe	Alstom (DongFang)	4 x 1000	2009-2011
	Shentou	Alstom (Beizhong)	2 x 660	2010
	Ningde	Alstom (DongFang)	4 x 1000	2010-2012
	FuQing	Alstom (DongFang)	4 x 1000	2010-2013
	Yangjiang	Siemens	6 x 1000	2010-2014
	Taishan 1 + 2	Alstom	2 x 1600	2011
	FangChengGang	Siemens	2 x 1000	2011/12
	Kashi	Shanghai Steam Turb.	2 x 350	2012
	Tangshan	Harbin Steam Turbine	2 x 350	2013
	Taizhou	Shanghai Steam Turbine	2 x 1000	2013
	Laiwu	Shanghai Steam Turbine	2 x 1000	2013

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Country	Power Plant	Manufacturer	Capacity (MW)	Delivery Date
China	Hami	Alstom (Beizhong)	2 x 660	2013
	Tianwan 3 + 4	Harbin Turbine (MHI)	2 x 1250	2014
	Wucaiwai	Alstom	2 x 660	2015
	Dabieshan	Alstom	2 x 660	2015
	Laizhou	Shanghai Turbines	2 x 1000	2016
	Yuxian	Shanghai Turbines	2 x 1000	2017
	Yuncheng	Dongfang	2 x 1000	2018
	Changjiang	Harbin	2 x 1000	2019
	Shidongkou	Shanghai Turbines	2 x 700	2020
Côte d'Ivoire	Ciprel IV	GE	110	2014
Croatia	Zagreb	Doosan Skoda	40	2018
Czech Republic	Prunero	Skoda		1989
	Olomouc	Foster Wheeler	40	1997
	Trebovice	Skoda	2 x 70	1998/2004
	Ledvice	Skoda	660	2010
Denmark	Asnaesvaerket	BBC Baden	600	1979
	Nefo 2	KWU	250	1976
	Sonderjyllands	KWU	630	1979
	Studstrup	BBC Baden	2 x 375	1981
	Fynsvaerket Bl. 7	Siemens	410	1989
	Oersted	Skoda	90	
	Vestkraft	ABB	400	
	Nordjyllandsvaerket	MAN Energie	414	1994
	Skaerbaekvaerket	MAN Energie	414	1994
	Avedore	Ansaldo	450	1999
	Lisbjerg Biomass	Doosan Skoda	39	2015
	Kalundborg	Doosan Skoda	25	2018
Estonia	Narva	Alstom	300	2012
Finland	Kainuun Voima	Siemens-KWU	84.6	1989
	Meri Pori	ABB Stal	580	1991
	Enso Gutzeit	MAN Energie	91.4	1991
	Oulu	LMZ	150	1992
	Oulu	Siemens-KWU	110	1995
	Alcholma	LMZ	250	1999
	Kymin Paper	Alstom	85	2001
	Olkiluoto	Siemens-KWU	1600	2005
	Tornio (Steel Plant)	Skoda	60	2006
	Juvaskyla	LMZ	200	2008
	Haapaniemi	Skoda	46	2010
	Raahe	LMZ	125	2014
	Hanhikivi	GE	1200	2018

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Country	Power Plant	Manufacturer	Capacity (MW)	Delivery Date
Finland	Salo	MAN		2019
France	Saint-Laurent-des-Eaux	Alsthom	2 x 900	1979
	Paluel	Alsthom	2 x 1300	1979
	Flamanville	Alsthom	2 x 1300	1980
	Golfech	Alsthom	2 x 1300	1980
	Chinon	Alsthom	4 x 900	1981
	Belleville	Alsthom	2 x 1300	1981
	Chooz	Alsthom	2 x 1500	1984
	Civaux	Alsthom	2 x 1500	1988
	Flamanville III	Alstom	1600	2007
	Dunkerque	M+M		2018
Germany	Stade	KWU	630	1968
	Biblis A	KWU	1145	1972
	Biblis B	KWU	1240	1972
	Neckarwestheim	KWU	775	1972
	Lausward	BBC	300	1973
	Gersteinwerk	BBC	4 x 400	1974
	Kalkar	KWU	300	1974
	Schmehausen	BBC	300	1974
	GKN 2	KWU	1300	1974
	Krümmel	KWU	1260	1975
	Brunsbüttel	KWU	770	1976
	Philipsburg	KWU	864	1976
	Isar	KWU	870	1976
	Mülheim-Kärlich	BBC	1300	1976
	Emsland	BBC	2 x 400	1976
	Grohnde	KWU	1300	1977
	Isar 2	KWU	1300	1977
	Staudinger	BBC	600	1978
	Reuter	BBC	190	1978
	Heyden	KWU	740	
	Hamborn	BBC	108	1978
	Stadtwerke Duisburg	BBC	140	1978
	Mehrum	KWU	660	1978
	Voerde A + B	BBC	650	1979
	Philipsburg 2	KWU	1300	1979
	Unterweser	KWU	1230	1980
	Wilhelmshaven	KWU	720	1980
	Weiher III	BBC	650	1980
	Walsum	KWU	410	1980
	Heilbronn	BBC	720	

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Country	Power Plant	Manufacturer	Capacity (MW)	Delivery Date
Germany	Bexbach	BBC	750	1981
	Bergkamen A	KWU	750	1982
	Gersteinwerk	KWU	750	
	Völklingen	KWU	195	1982
	GKM	BBC	2 x 200	
	GKM	BBC	84	
	Ibbenbüren	KWU	740	1982
	Völklingen	Siemens-KWU	210	1982
	Leiningerwerk	BBC	450	1983
	Elverlingsen	BBC	315	1983
	Grafenrheinfeld	KWU	1300	1983
	Gundremmingen	KWU	2 x 1300	1983
	Brokdorf	KWU	1360	1983
	Rheinhafen	BBC	550	1983
	Hastedt	BBC	130	
	VW/CHP West	KWU	2 x 130	
	Stadtwerke Duisburg	KWU	95.8	
	GKW Hannover	KWU	2 x 145	
	Herne IV	KWU	500	1983
	Moabit	Siemens KWU	110	1988
	Staudinger 5	ABB	600	1990
	Tiefstack	MAN Energie	160	1990
	Rostock	ABB	500	1992
	Dresden Nossener Brücke	Siemens-KWU	72,5	1993
	Schkopau	Siemens-KWU	110	1993
	Schkopau	ABB	2 x 450	1993
	Schwarze Pumpe	Siemens-KWU	2 x 800	1994
	Altbach	Siemens-KWU	345	1995
	Lippendorf A + B	ABB	2 x 900	1996
	Boxberg	Siemens-KWU	900	1996
	VW Nord	Siemens-KWU		1998
	Niederaußem	Siemens-KWU	1000	1999
	München Süd	Alstom	100	2003
	Neurath	Alstom	2 x 1100	2007
	Walsum	Hitachi	750	2007
	Datteln	Alstom	2 x 900	2007
	Boxberg	Alstom	900	2007
	Salzgitter	Siemens		2007
	Hoechst	Skoda	86	2008
	Moorburg	Alstom	2 x 900	2009
	Wilhelmshaven	Siemens-KWU	2 x 145	2009

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Country	Power Plant	Manufacturer	Capacity (MW)	Delivery Date
Germany	Lünen	Siemens	900	2009
	RDK Karlsruhe	Alstom	900	2009
	Wilhelmshaven	Hitachi	750	2009
	GKM9	Alstom	900	2010
	Holzkirchen	Turboden		2017
	Kassel	M+M		2020
Great Britain	Templeborough	Doosan Skoda	45	2015
	Dunbar	Doosan Skoda	38	2015
	Margam	Doosan Skoda	45	2015
	Gloucester	MAN		2016
	Port Talbot	MAN		2018
Greece	Megalopolis	KWU	300	1970
	Komotini	Ansaldo	175	1999
Hungary	Csepel II	GE		1998
India	Trombay 6	Siemens	500	1987
	Anta	BBC	150	1988
	Dadri	BHEL	4 x 210	1989
	Talcher	ABB	2 x 500	1991
	Dahanu	BHEL	2 x 250	1991
	Gandhar	ABB	210	1992
	Suratgarh	BHEL	5 x 250	1994
	Chandrapur	BHEL	500	1994
	Khaparkheda	BHEL	2 x 210	1994
	Unchahar	BHEL	3 x 210	1996
	Vindhyachal	BHEL	4 x 500	1996
	Kayamkulam	BHEL	350	1997
	Soda Ash	Shin Nippon	2 x 16.34	1998
	Simhadri	BHEL	2 x 500	1999
	Neyveli	Alstom	250	2000
	Talcher	BHEL	4 x 500	2001
	Akrimota	Ansaldo	2 x 125	2001
	Rihand	BHEL	2 x 500	2002
	Ramagundam	BHEL	500	2002
	Kota	BHEL	195	2002
	Panipat	BHEL	2 x 250	2002
	Paricha	BHEL	2 x 210	2003
	Bellary	BHEL	500	2004
	Rayalaseema	BHEL	2 x 210	2004
	Birsingpur	BHEL	500	2004
	Kahalgaon	BHEL	3 x 500	2004
	New Parli	BHEL	250	2004

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Country	Power Plant	Manufacturer	Capacity (MW)	Delivery Date
India	Korba East	BHEL	2 x 250	2004
	Sipat	BHEL	2 x 500	2004
	Sipat	LMZ	3 x 660	2004
	Kundankulam	LMZ	2 x 1000	2004
	Barh	LMZ	3 x 660	2004
	Giral Lignite	BHEL	125	2005
	Lehra Mohabbat	BHEL	2 x 250	2005
	Paras	BHEL	250	2005
	Santaldih	BHEL	250	2005
	Amarkantak	BHEL	210	2005
	Vijayawada	BHEL	500	2006
	Bhoopalapally	BHEL	500	2006
	Neyveli	BHEL	2 x 250	2006
	Tata Power	BHEL	120	2007
	New Parli	BHEL	250	2007
	Paras	BHEL	250	2007
	Dadri	BHEL	2 x 490	2007
	Paricha	BHEL	2 x 250	2007
	Farakka	BHEL	500	2007
	Korba	BHEL	500	2007
	Tau Devi Lal	BHEL	2 x 250	2007
	Mejia 'B'	BHEL	2 x 500	2007
	Koderma	BHEL	2 x 500	2007
	Durgapur Steel	BHEL	2 x 500	2007
	Kothagudem	BHEL	1 x 500	2007
	Giral Lignite	BHEL	1 x 125	2007
	Harduaganj	BHEL	2 x 250	2008
	Simhadri-II	BHEL	2 x 500	2008
	Aravali	BHEL	3 x 500	2008
	Ennore	BHEL	2 x 500	2008
	Khaperkheda	BHEL	1 x 500	2008
	Bhusawal	BHEL	2 x 500	2008
	Rayalseema	BHEL	1 x 210	2008
	Santaldhi	BHEL	1 x 250	2008
	Bellary	BHEL	1 x 500	2008
	Raichur	BHEL	1 x 250	2008
	Mauda	BHEL	2 x 500	2009
	Anpara	BHEL	2 x 500	2009
	Ukai	BHEL	1 x 490	2009
	Bongaigaon	BHEL	3 x 250	2009
	Rihand	BHEL	2 x 500	2009

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Country	Power Plant	Manufacturer	Capacity (MW)	Delivery Date
India	Vindhyachal	BHEL	2 x 500	2009
	Marwa	BHEL	2 x 500	2009
	Korba West Extn.	BHEL	1 x 500	2009
	Barh-II	BHEL	2 x 660	2009
	Avantha	BHEL	600	2010
	Tuticorin	BHEL	2 x 500	2010
	New Parli	BHEL	250	2010
	Chandrapur	BHEL	2 x 500	2010
	Bokaro	BHEL	500	2010
	Vallur-I	BHEL	500	2010
	Sagardighi	BHEL	2 x 500	2011
	Bhavnagar	BHEL	2 x 250	2011
	Nabinagar	BHEL	4 x 250	2011
	Jhabua	BHEL	600	2011
	Muzaffarpur	BHEL	2 x 195	2011
	Meja	Toshiba	2 x 660	2012
	Solapur	Alstom	2 x 660	2012
	Singareni	BHEL	2 x 600	2013
	Kudgi	Toshiba	3 x 800	2013
	Mauda	BHEL	2 x 660	2013
	Vindhyachal	BHEL	500	2013
	Raghunathpur	BHEL	2 x 660	2014
	Nabinagar	Alstom	2 x 660	2014
	Lara	Hitachi	2 x 800	2014
	Gadarwara	BHEL	2 x 800	2014
	Unchahar	BHEL	500	2014
	Neyveli	BHEL	2 x 500	2014
	Nabinagar	Alstom	3 x 660	2015
	Darlipali	Toshiba	2 x 800	2015
	Tanda	Alstom	2 x 660	2015
	Ennore	Dongfang	660	2015
	Raigarh	BHEL	600	2016
	Sagardighi	BHEL	500	2016
	North Chennai	BHEL	800	2017
	Uppur	BHEL	2 x 800	2018
	Godda	GE China	800	2018
	Kudankulam	Toshiba	3 x 1000	2018
Indonesia	Medan	Alstom	2 x 65	1981
	Cilacap	Shanghai	1 x 1000	2017
Ireland	Moneypoint	BBC Baden	4 x 350	1983
	Lough Ree	Fuji	100	2003

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Country	Power Plant	Manufacturer	Capacity (MW)	Delivery Date
Ireland	West Offaly	Fuji	150	2003
Israel	Rutenberg	ABB	2 x 550	1996
Italy	Sermide	Franco Tosi	350	1980
	Tavazzano	Franco Tosi	2 x 320	1980
	Fiume Santo	Ansaldo	2 x 320	1987
	Pietrafitta	Ansaldo	2 x 75	1992
	Sulcis	Ansaldo	320	2004
	Modugno	Alstom	250	2007
Kazakhstan	Pawlodar		120	2018
Korea	Ulsan	BBC Baden	3 x 400	1978
	Seoul City	Doosan	2 x 400	2014
Kuwait	Az Zour	Toshiba	8 x 300	1992
	Doha West	Mitsubishi	8 x 300	
	Sabiya	Mitsubishi	8 x 300	1989
	Shuaiba North	Toshiba	216	2008
Malaysia	Port Kelang	Mitsubishi	2 x 300	1986
	Port Kelang	GE	500	
	Saba Shipyard		100	1994
	Mentakab	ABB Turbinen		1997
	Manjung 4	Alstom	1000	2012
	Tanjung Bin 4	Alstom	1000	2013
	Manjung 5	Hitachi	1000	2014
Morocco	Jorf Lasfar	Mitsubishi	2 x 350	2011
Netherlands	Hemweg 7	BBC	500	1975
	Amercentrale	BBC	600	1980
	Centrale Velsen	KWU	360	1982
	Amer 9	ABB		1989
	Hemweg 8	ABB	500	1990
	Moerdijk	Siemens-KWU	150	1994
	Rotterdam (Maasvlakte)	Hitachi	750	2009
	Rotterdam (Maasvlakte)	Alstom	900	2010
Nigeria	Bouygues	Hitachi	6 x 250	1982
Northern Ireland	Coolkeeragh	Alstom	144	2003
Pakistan	Lucky Electric	GE China	660	2018
Poland	Zeran	Siemens Industrial Brno	100	2005
	EC Siekierki	Siemens	110	2008
	Czestochowa	Alstom	65	2008
	Konin		55	2011
	EC Zoflowka	Siemens	75	2015
	Rybnik	Alstom	900	2012

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Country	Power Plant	Manufacturer	Capacity (MW)	Delivery Date
Poland	Opole	Alstom	2 x 900	2015
	Kozienice	Mitsubishi Hitachi	1000	2015
Portugal	Sines	BBC Baden	4 x 300	1985
	Pego	ABB Baden	2 x 300	1989/1992
Romania	Bucuresti Vest	Siemens		2006
Russia	TEZ St. Petersburg North-West	LMZ	2 x 150	1995
	TEZ-2 Saransk	LMZ	65	1998
	Juschno-Kusbasskaja GRES	LMZ	115	2001
	Tjumen	ABB	50	2003
Russia	TEZ Süd-West St. Petersburg	LMZ	2 x 150	2000/06
	TEZ-27 Moskau	LMZ	2 x 150	2007
	TEZ-21 Moskau	LMZ	150	2007
	TEZ-22 St. Petersburg-Süd	LMZ	150	2008
	TEZ-2 Kaliningradskaja	LMZ	2 x 150	2009
	TEZ-5 Prawobereschnaja	LMZ	150	2009
	TEZ-6 Perm	Siemens	30	2010
	Nowourengoiskaja GRES	LMZ	1 x 150	2010
	Nowourengoiskij GHK	SNM	40	2011
	Belojarskaja	LMZ	800	2012
	Leningradskaja	LMZ	2 x 1200	2012
	Bratsk	KTZ	2 x 30	2013
	Nowoworeneschkaja	LMZ	2 x 1200	2011/13
	TEZ-5 Ufinskaja	LMZ	2 x 80	2010/15
	Jaroslavskaja	LMZ	1 x 150	2014
	Belorusskaja	LMZ	2 x 1200	2015
Saudi Arabia	Zatonskaja TEZ	Doosan Skoda	60	2015
	Shoaiba 1 – 3	ABB	5 x 393	1999
	Shoaiba 4 – 5	Alstom	2 x 390	2001
	Shoaiba 9 - 11	Alstom	3 x 390	2004
	Shoaiba 12 - 14	Alstom	3 x 390	2008
	Shuqaiq	Alstom	4 x 720	2014
Singapore	Yanbu 3	Alstom	5 x 620	2014
	Tuas South	MHI	2 x 66	1998
Slovenia	Sostanj IV	KWU	335	1978
Spain	Trillo	KWU	1300	1982
	Pontevedra	M+M		2018
Sri Lanka	Kerawalapitiya	GE	100	
Sweden	Nyköping	ABB STAL	80	1993
	Malmö	Hitachi Power	161	2007
	Värtaverket	Doosan Skoda	154	2013

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Country	Power Plant	Manufacturer	Capacity (MW)	Delivery Date
Sweden	Södra Cell VÄRÖ	Doosan Skoda	55	2015
	Sveg	M+M		2016
Switzerland	Gösgen	KWU	920	1974
	Leibstadt	BBC	900	1974
	Genf	Fincantieri	12	2018
Taiwan	Taitung	Alstom Brno		2001
Thailand	Khanom	Alstom	75	1988
Turkey	Baymina	Alstom	320	2002
	Karabiga	Alstom Beijing	2 x 660	2015
	Hunutlu	Shanghai Turbines	2 x 660	2016
UAE	Deep	ABB		1992
	Jebel Ali	ABB		1994
	Jebel Ali	ALSTOM	2 x 120	2006
	Jebel Ali L	ALSTOM	221	2008
	Jebel Ali M	ALSTOM	3 x 221	2008
Ukraine	Smart Energy	M+M		2020
Uruguay	ENCE/Montes del Plata	Siemens	2 x 90	2011
USA	El Centro/CA	Siemens	60	2011
	Vogtle	Toshiba	2 x 1000	2011/12
	Virgil C. Summer	Toshiba	2 x 1000	2012/13
Venezuela	Cadafé	KWU	2 x 400	1976
	Cadafé	BBC	2 x 400	1982

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