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

TERRAPOWER, LLC – FINAL SAFETY EVALUATION OF TOPICAL REPORT NATD-LIC-RPRT-0002, "PRINCIPAL DESIGN CRITERIA FOR THE NATRIUM ADVANCED REACTOR," REVISION 1 (EPID L-2021-TOP-0020)

SPONSOR AND SUBMITTAL INFORMATION

Sponsor:	TerraPower, LLC
Sponsor Address:	15800 Northup Way Bellevue, WA 98008
Project No.:	99902100
Submittal Date:	April 10, 2024

Submittal Agencywide Documents Access and Management System (ADAMS) Accession Nos.: ML23024A280; ML24101A362

Brief Description of the Topical Report: By letter dated January 24, 2023 (ML23024A280), TerraPower, LLC (TerraPower) submitted a Topical Report (TR) entitled, "Principal Design Criteria for the Natrium Advanced Reactor," Revision 0, for the U.S. Nuclear Regulatory Commission (NRC) staff's review. By letter dated April 10, 2024, TerraPower submitted Revision 1 of the TR. The TR describes the result of TerraPower's process to develop Principal Design Criteria (PDC) for the Natrium advanced reactor and specifically addresses compliance with the construction permit application requirement under Title 10 of the *Code of Federal Regulations* (10 CFR) 50.34(a)(3)(i). TerraPower requested the NRC's review and approval of these PDC for use by future applicants using the Natrium reactor design under 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities." TerraPower also requested approval of its rationale for meeting the intent of Natrium PDC 26, "Reactivity control systems."

TerraPower's overall licensing approach for the Natrium reactor design follows the Licensing Modernization Project (LMP) methodology described in Nuclear Energy Institute (NEI) 18-04, Revision 1, "Risk-Informed Performance-Based Technology Inclusive Guidance for Non-Light Water Reactor Licensing Basis Development" (ML19241A472). Regulatory Guide (RG) 1.233, "Guidance for a 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. TerraPower used RG 1.232, "Guidance for Developing Principal Design Criteria for Non-Light-Water Reactors," Revision 0, (ML17325A611) to inform the development of its PDC for the Natrium reactor.

By email dated March 17, 2023, the NRC staff informed TerraPower that the TR provided sufficient information for the NRC staff to conduct a detailed technical review (ML23074A349). On August 22, 2023, the NRC staff transmitted an audit plan to TerraPower (ML23201A247), and subsequently conducted an audit of materials related to the TR from September 7, 2023, to October 5, 2023. The audit summary was issued on January 30, 2024 (ML24051A029).

REGULATORY EVALUATION

The provisions of 10 CFR 50.34(a)(3)(i) require construction permit applicants to include PDC as part of the preliminary safety analysis report (PSAR) for a proposed facility. The required preliminary design information that must also be provided as part of the PSAR includes (1) the design bases and the relation of the design bases to the PDC in accordance with 10 CFR 50.34(a)(3)(ii), and (2) "[i]nformation relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety" in accordance with 10 CFR 50.34(a)(3)(iii).

The regulations under 10 CFR 50.34(a)(3)(i) state, in part, that "Appendix A [to 10 CFR Part 50], 'General Design Criteria for Nuclear Power Plants,' establishes minimum requirements for the [PDCs] for water-cooled nuclear power plants similar in design and location to plants for which construction permits have previously been issued by the Commission and provides guidance to applicants in establishing PDCs for other types of nuclear power plant units." Since the Natrium design is a sodium-cooled fast reactor (SFR), PDCs are required but they are not required to align with the minimum requirements in the general design criteria (GDCs) in 10 CFR Part 50, Appendix A. Nonetheless, the introduction to 10 CFR Part 50, Appendix A, generally describes the PDCs as "establish[ing] the necessary design, fabrication, construction, testing, and performance requirements for structures, systems, and components important to safety; that is, structures, systems, and components that provide reasonable assurance that the facility can be operated without undue risk to the health and safety of the public."

Recognizing that the GDCs in 10 CFR Part 50, Appendix A may not be appropriate for non-light-water reactors (non-LWRs), the NRC issued RG 1.232, Revision 0, which serves as guidance for developing PDCs for non-LWR designs. RG 1.232, Appendix B, "Sodium-Cooled Fast Reactor Design Criteria," provides the guidance for SFR design criteria (DC).

The NRC issued RG 1.233 which 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. As previously noted, RG 1.233 endorsed (with clarifications and points of emphasis) NEI 18-04. Industry-developed guidance for content of applications using NEI 18-04 is provided in NEI 21-07, "Technology Inclusive Guidance for Non-Light Water Reactors – Safety Analysis Report: For Applications Utilizing the NEI 18-04 Methodology," Revision 1 (ML22060A190). NEI 21-07 is endorsed with clarifications and additions by RG 1.253, "Guidance for a Technology-Inclusive Content of Application Methodology to Inform the Licensing Basis and Content of Applications for Licenses, Certifications, and Approvals for Non-Light-Water Reactors," Revision 0 (ML23269A222).

TECHNICAL EVALUATION

1. Natrium Design Features

Section 1 "Natrium Advanced Reactor Design Features," of the TR provides an overview of the key design features of the TerraPower Natrium reactor. The Natrium design is a pool-type, metal-fueled SFR where the reactor heats sodium in the primary heat transport system and transfers the heat via an integral heat exchanger to the intermediate sodium loop. The intermediate loop transfers this heat to sodium-salt heat exchangers where it heats a molten salt loop. Molten salt is pumped between the sodium-salt heat exchangers and the energy island, where it can be stored and converted to electricity.

The TR states that the Natrium design utilizes “metal fuel.” Additional detail on the fuel design is provided in TerraPower TR NATD-FQL-PLAN-0004, “Fuel and Control Assembly Qualification,” Revision 0 (ML23025A409), which was submitted to the NRC staff for review in January 2023, and addresses fuel and control assembly qualification. The proposed Type 1 fuel that will be in the initial Natrium core consists of metallic uranium-zirconium alloy slugs contained in right cylindrical fuel rods, arranged in a triangular pitch to form hexagonal fuel assemblies.

Though not discussed in the TR, the Natrium plant’s safety-related (SR) means of residual heat removal is discussed in various other licensing submittals from TerraPower, including its approved topical report TR-NATD-LIC-RPRT-0001-A, “Regulatory Management of Natrium Nuclear Island and Energy Island Design Interfaces,” Revision 0 (ML24011A321). In TR NATD-LIC-RPRT-0001-A, the SR residual heat removal system is referred to as the reactor air cooling system (RAC). The RAC cools the reactor by supplying natural draft outside ambient air down into the reactor cavity and past the outside of the reactor. The RAC is an open, passive system that is always in operation.

2. PDC Development Methodology

Section 4, “PDC Development Methodology,” of the TR describes TerraPower’s process for developing the Natrium PDCs; TR Figure 1, “PDC Development Flowchart,” summarizes the process. TerraPower stated that it first reviewed and adopted the SFR-DC from Appendix B to RG 1.232, where possible. Where the Natrium design was not well represented by the SFR-DC, TerraPower stated that it reviewed the language from the GDC and the other RG 1.232 appendices (i.e., Appendix A, “Advanced Reactor Design Criteria,” (ARDC)[1] and Appendix C, “Modular High-Temperature Gas-Cooled Reactor Design Criteria” (MHTGR-DC)) to determine if a criterion could be modified, or if a new PDC would be required.

The NRC staff considers this overall approach to be acceptable as it uses the NRC staff approved guidance in RG 1.232 as a basis for developing Natrium design-specific criteria.

3. Evaluation of Natrium Principal Design Criteria

Section 5, “Summary of Changes to the RG 1.232 Design Criteria,” of the TR provides TerraPower’s justification for the types of changes it made to the RG 1.232 DC to ensure that the Natrium PDCs collectively provide a comprehensive design and regulatory framework for the Natrium advanced reactor. Table 2, “Natrium Principal Design Criteria,” of the TR contains a list of the Natrium PDCs, the source language (e.g., SFR-DC, MHTGR-DC), and the basis for adaptations.

The NRC staff’s review was limited to an evaluation of the PDCs in the context of the proposed Natrium plant design and did not include a detailed review of how TerraPower intends for the

[1] As stated in RG 1.232, “The NRC intends the ARDC to apply to the six advanced reactor technology types identified in the DOE report [titled ‘Guidance for Developing Principal Design Criteria for Advanced (Non-Light Water) Reactors,’ December 2014 (ML14353A246, ML14353A248)]; however, in some instances, one or more of the criteria from the SFR-DC or MHTGR-DC may be more applicable to a design or technology than the ARDC.”

design to meet the PDCs (e.g., specific design limits associated with DC). Additionally, the NRC staff notes that any requests for exemptions from NRC regulations necessary to support use of these PDCs should be addressed in separate licensing actions.

3.1 General Changes to RG 1.232 DC

3.1.1 Use of the Term "Safety-Significant"

Section 5.1, "Use of Safety-Significant and Addition of Safety-Significant Language," of the TR summarizes TerraPower's changes to various DC in RG 1.232 to align with the approach outlined in NEI 18-04. Specifically, the term "important to safety" from the GDC and DC in RG 1.232 is replaced with "safety-significant" in Natrium PDC 1-5, 16-18, 20, 44, 61, 72, 73, 75, 77, and 78.

In 10 CFR Part 50, Appendix A, structures, systems, and components (SSCs) that are classified as "important to safety" are those "that provide reasonable assurance that the nuclear power plant can be operated without undue risk to the health and safety of the public." By contrast, NEI 18-04 defines "safety-significant" SSCs as those SSCs that are classified as either SR or non-safety-related with special treatment (NSRST) using the NEI 18-04 safety classification process. However, NRC staff position C.6.a.(2) of RG 1.253 states, "For applicants using the LMP process endorsed in RG 1.233, SSCs important to safety include both SR and NSRST SSCs."

Additional guidance on the scope of PDCs is provided in DANU-ISG-2022-01, "Review of Risk-Informed, Technology-Inclusive Advanced Reactor Applications—Roadmap" (ML23277A139), Section 1.1.4, "Developing Proposed Principal Design Criteria (PDC) for Those Aspects of the Facility Design not Informed by the LMP Process (e.g., Normal Operations)." This document clarifies that there may be certain design functions and features that are not informed by LMP, because they relate to normal operation, that are still important to the protection of public health and safety. As an example, the ISG refers to PDCs developed for radiation protection. Such design functions and features would accordingly need PDCs. Though TerraPower's proposed PDCs replace "important to safety" with "safety significant," the NRC staff determined that they adequately cover the kinds of design functions and features discussed in DANU-ISG-2022-01 because (1) the term "safety-significant" appropriately encompasses the SSCs that should be addressed by the proposed PDCs using that term, and (2) TerraPower's proposed PDCs are based on the RG 1.232 DC rather than being limited to SR and NSRST SSCs covered by the process laid out in NEI 18-04 and NEI 21-07. Examples include proposed PDCs 60, 61, and 64, which explicitly relate to managing and monitoring effluents from normal operations.

For the reasons given above, the NRC staff considers use of the term "safety significant" to be acceptable in the applicable Natrium PDCs.

3.1.2 Use of Graded Approach to Coolant Boundary Quality

TerraPower provided a change to numerous RG 1.232 DCs, including 13, 14, 15, 28, 30, 31, 32, and 76, to refer to safety-significant elements or portions of the primary or intermediate coolant boundaries rather than the entire primary or intermediate coolant boundary. This change is discussed briefly in the basis for changes to PDC 14, where it is noted that portions of the reactor coolant boundary have greater safety significance than others and that different degrees of safety significance should align with different quality standards and design requirements. For clarity, the NRC staff notes that the reference DCs for Natrium PDCs 1, 2, 61, 75, 77 already addressed a graded approach to quality but were modified with conforming "safety-significant" language as discussed in Section 3.1.1 of this safety evaluation (SE).

By referencing the "safety-significant elements" of the primary or intermediate coolant boundary in these PDCs, TerraPower implies that not all of the primary or intermediate coolant boundaries are necessarily safety significant. The NRC staff notes that 10 CFR 50.2, "Definitions," provides a definition for SR SSCs that includes those SSCs "relied upon to remain functional during and following design basis events to assure…[t]he integrity of the reactor coolant pressure boundary." It is possible that TerraPower could identify all elements of the primary coolant boundary as SR using the NEI 18-04 safety classification process, which would provide consistency between the Natrium PDC and the 10 CFR 50.2 definition. However, it is also possible that TerraPower could identify some elements of the primary coolant boundary as NSRST or NST, which would be consistent with the Natrium PDC, but not the 10 CFR 50.2 definition.

When endorsing NEI 18-04, the NRC staff anticipated differences between SR SSC classification under the NEI 18-04 process and the 10 CFR 50.2 definition. RG 1.233 notes that "the term 'safety-related' in NEI 18-04 for non-LWRs is not the same as the definition in 10 CFR 50.2, and the SSCs included in the 'safety-related' classification for non-LWRs may not be the same as those considered SR for LWRs." RG 1.233 further reinforces this by setting an expectation that applicants using the NEI 18-04 process for safety classification will "as needed, identify exceptions to and exemptions needed from NRC regulations." If, in the course of its application of the NEI 18-04 process for safety classification, TerraPower identifies that some elements of the primary coolant boundary are not classified as SR under the NEI 18-04 process, an exemption from NRC regulations may be needed.

However, the NRC staff finds it reasonable that an applicant using the NEI 18-04 process would not necessarily identify all components of the primary coolant boundary as SR. The NRC staff expects that proper application of the NEI 18-04 process would result in quality, design, and performance requirements that are commensurate with the safety significance of the SSCs and capable of providing adequate protection of public health and safety. Accordingly, the NRC staff finds the aforementioned changes to the RG 1.232 DCs acceptable because the changes are consistent with implementation of the NEI 18-04 methodology.

3.1.3 Use of Specified Acceptable System Radionuclide Release Design Limit

Section 5.2, "Use of Specified Acceptable System Radionuclide Release Design Limit," of the TR describes the basis for TerraPower's adoption of the concept of specified acceptable system radionuclide release design limits (SARRDLs) in the Natrium PDC. In Natrium PDCs 10, 12, 26, 33, 34, and 78, the SARRDLs replace the specified acceptable fuel design limits (SAFDLs) used in the RG 1.232 SFR-DC.

As noted in TR Section 5.2 and in the basis for changes to Natrium PDC 10, the SARRDL concept was initially developed for MHTGRs to reflect the performance and characteristics of coated particle fuel (e.g., tri-structural isotropic particle fuel, or TRISO fuel). The TRISO fuel envisioned for the MHTGR differs significantly from the metallic fuel proposed for the Natrium design, as discussed in SE Section 3.1. However, TerraPower stated in Section 5.2 of the TR that "the endorsement of a technology-inclusive [risk-informed performance-based (RIPB)] licensing basis methodology," as discussed in RG 1.233 and NEI 18-04, "makes the SARRDL concept accessible for all non-LWR developers."

The NRC staff notes that RG 1.233 and NEI 18-04 stress the importance of evaluating the effectiveness of radionuclide barrier performance in a RIPB framework, but this is discussed in the context of functional containment performance rather than SARRDLs specifically. However, as stated in SECY-18-0096, "Functional Containment Performance Criteria for Non-Light-Water-Reactors" (ML18115A157), SARRDLs represent a performance-based approach for determining functional containment performance criteria that is applicable to any non-LWR design. As discussed in SECY-18-0096 and RG 1.232, the functional containment and SARRDL concepts are fundamentally intertwined.

TerraPower stated that it intends to pursue a functional containment approach in the Natrium design, as discussed below. TerraPower also stated in the basis for changes to SFR-DC 10, that informs Natrium PDC 10, that the Natrium SARRDLs will "fulfill the same intent described in RG 1.232 and will be established so that (1) the consequences of the most limiting design basis accident does not exceed the siting regulatory dose limits criteria at the exclusion area boundary (EAB) and low-population zone, and (2) the 10 CFR 20.1301 annualized dose limits are not exceeded at the EAB for normal operation and [anticipated operational occurrences (AOOs)]." The discussion regarding Natrium PDC 10 also indicates that the use of SARRDLs relies on the design's low pressure, the use of a single-phase reactor coolant (liquid sodium), and the ability of the coolant to retain certain fission products released from failed fuel.

The NRC staff finds that the use of SARRDLs in the Natrium PDCs is acceptable because: (1) the SARRDLs provide an appropriate performance-based approach to determining functional containment performance criteria consistent with the licensing methodology that TerraPower intends to use; (2) TerraPower is using both SARRDLs and a functional containment approach; and (3) the TR provides that an applicant establishing the SARRDLs for the Natrium design would follow the same basis for SARRDL-related PDCs as RG 1.232. The NRC staff also considered various aspects of the Natrium design discussed in the TR, including the use of a single-phase coolant operating at near atmospheric pressure and high reliability fuel. These features are necessary for SARRDLs to be applicable to the plant design and give the NRC staff confidence that TerraPower can establish appropriate SARRDLs with which they can comply.

3.1.4 Use of Functional Containment Concept

Section 5.3.1, "Functional Containment," of the TR discusses the use of the functional containment concept for the Natrium design. A "functional containment" is defined in Appendix C to RG 1.232 as a "barrier, or set of barriers taken together, that effectively limit the physical transport and release of radionuclides to the environment across a full range of normal operating conditions, AOOs, and accident conditions." Incorporation of a functional containment concept into the Natrium PDCs results in the use of language from MHTGR-DC 16, adoption of SFR-DC 64 with modifications, exclusion of PDCs 38-43 and 50-57, and the addition of PDCs 81 and 82, which are derived from MHTGR-DC 81 and 82. Use of the functional containment concept is also related to the use of SARRDLs, as discussed in SE Section 3.1.3.

TerraPower's rationale for the use of a functional containment concept is summarized in TR Section 5.3.1 as follows: "the functional containment concept is RIPB, and complements the mechanistic source term, use of SARRDL, and overall [LMP] methodology endorsed in RG 1.233." TerraPower also notes that the Commission has previously found the functional containment concept generally acceptable, as indicated in various staff requirements memoranda (SRMs). TerraPower asserts that a functional containment strategy is viable because the Natrium reactor has substantial margin to its coolant boiling point, operates at near atmospheric pressure, and is not susceptible to loss-of-coolant accidents, which have historically driven the adoption of pressure-retaining containments as seen in the operating LWR fleet. Section 5.3.1 of the TR also summarizes the design features that serve as Natrium's functional containment barriers.

SRM-SECY-18-0096 (ML18338A502) indicates that the use of a functional containment approach necessitates the identification of performance criteria for SSCs that play a role in radionuclide retention. It documents a proposed RIPB process for developing functional containment performance criteria that takes advantage of mechanistic source term analyses. The licensing process discussed in NEI 18-04 and RG 1.233 aligns with the process documented in SECY-18-0096. Because TerraPower is using the NEI 18-04 process, the NRC staff determined that TerraPower has an acceptable approach to identifying functional containment performance criteria and therefore the use of a functional containment approach is consistent with SECY-18-0096.

As discussed in SE Section 3.1.3, the NRC staff also considered key design features (discussed in the TR and in Section 1 of this SE) of the Natrium design in determining whether the functional containment approach is applicable to the design. Many of these features are necessary for the functional containment approach to be viable for Natrium, particularly those design features that make the reactor coolant boundary less susceptible to energetic releases (e.g., use of near atmospheric pressures, prevention of coolant boiling, removal of the potential for sodium-water interactions). Accordingly, the NRC staff determined changes, additions, or deletions to the aforementioned PDCs to accommodate the Natrium functional containment concept are acceptable. However, like the previous discussion on SARRDLs, the NRC staff's review did not encompass specific functional containment barriers and performance criteria applicable to the Natrium design.

3.1.5 Adoption of MHTGR-DC with MHTGR-Specific Language Removed

As discussed in TR Section 5.4, "Natrium Specific Language," TerraPower found various MHTGR-DCs from RG 1.232 that are applicable to the Natrium design and proposed to adopt them with changes to remove MHTGR-specific terminology. MHTGR-DCs are used as the basis for Natrium PDCs 13, 16, 20, 25, 80, 81, and 82. Of these, PDCs 13, 81, and 82 have changes that remove references to the reactor helium pressure boundary or pathways in the reactor building to accommodate reactor helium in the event of a depressurization accident.

The NRC staff recognizes that the Natrium design does not have a helium pressure boundary and does not need a helium depressurization pathway, even if the MHTGR-DC are otherwise technically appropriate for Natrium. As such, the NRC staff finds these changes to be acceptable. Applicability of selected MHTGR-DC to Natrium is addressed in SE Section 3.2.2.

3.1.6 Use of the Term "Safe Shutdown"

Section 5.4 of the TR describes a change to certain SFR-DCs (5 and 19) to use the language "safe shutdown" rather than "shutdown and cooldown" or "cold shutdown". The basis for the change to SFR-DC 5, to inform Natrium PDC 5, is described in the TR as necessary to "remove the implied temperature of 'cooldown'" because the Natrium reactor coolant melting temperature is significantly higher than ambient temperature. TerraPower stated that the proposed "safe shutdown" language is based on considerations provided in the rationale for ARDC 26 in RG 1.232 and SECY-94-084, "Policy and Technical Issues associated with the Regulatory Treatment of Non-Safety Systems in Passive Plant Designs" (ML003708068). The rationale for

ARDC 26 in Appendix A to RG 1.232, sentence (4), indicates that, consistent with the discussion in SECY-94-084, cold shutdown was historically needed to inspect and repair a plant following an accident. The NRC staff noted in SECY-94-084 that plant conditions other than traditional cold shutdown “may constitute a safe shutdown state as long as reactor subcriticality, decay heat removal, and radioactive materials containment are properly maintained for the long term.” ARDC 26 was accordingly modified from GDC 26 to remove the reference to cold shutdown and instead state that a system is needed to hold the reactor subcritical during "interventions such as refueling, inspection, and repair.” It is the NRC staff’s understanding, based on the adoption of the ARDC 26 language in Natrium PDC 26, that TerraPower’s “safe shutdown” condition represents a condition under which these interventions can be accomplished.

The NRC staff notes that the recommendation approved by the Commission in SRM-SECY-94-084 (ML003708098) was to accept a safe shutdown condition of 215.6 degrees Celsius in lieu of cold shutdown; the recommendation was “predicated on an acceptable passive safety system performance and acceptable resolution of the issue of regulatory treatment of non-safety systems.” For the Natrium design, performance of the passive decay heat removal system is addressed by other PDCs, including PDC 34-37, and the regulatory treatment of non-safety systems is addressed through use of NEI 18-04 and RG 1.233.

The NRC staff finds the aforementioned changes to SFR-DC 5 and 19, as these inform Natrium PDCs 5 and 19, acceptable because the NRC staff considers the use of “safe shutdown” rather than “shutdown and cooldown” or “cold shutdown” to be acceptable and consistent with the discussion in RG 1.232, the Commission-approved recommendation in SECY-94-084, and the Natrium design and licensing approach.

3.1.7 Leak-Tightness of Cooling Systems

In Natrium PDCs 37 and 46, addressing testing of emergency core cooling systems and structural and equipment cooling systems, TerraPower made a change to remove the word “leaktight” from SFR-DCs 37 and 46 when discussing component integrity of these systems. As discussed in the basis for changes applicable to both PDCs, RG 1.232 notes that “a non-leaktight system may be acceptable for some designs provided that (1) the system leakage does not impact safety functions under all conditions, and (2) defense in depth is not impacted by system leakage.”

The Natrium design uses an open, natural draft air circulation system for emergency core cooling in accident scenarios, where some amount of leakage would not be anticipated to impact performance of the system. Accordingly, the NRC staff finds the aforementioned changes to SFR-DCs 37 and 46 to inform Natrium PDCs 37 and 46, respectively, acceptable because it is reasonable for the system to be able to maintain safety while not being completely leaktight.

3.2 Evaluation of Specific Natrium Principal Design Criteria

Table 2 of the TR contains each Natrium PDC, the source language (e.g., SFR-DC, MHTGR-DC), and the basis for adaptations.

3.2.1 SFR-DC-derived PDCs

Many of the Natrium PDCs are derived from the SFR-DCs in Appendix B to RG 1.232, including PDCs 1-12, 14, 15, 17-19, 21-24, 26, 28-37, 44-46, 60-64, and 70-79. Beyond those subjects considered in the GDCs, the SFR-DCs cover SFR-specific subjects, including the intermediate system, coolant and cover gas purity control, cover gas inventory maintenance, sodium heating systems, and issues related to the chemical reactivity of sodium (including leakage detection, sodium/water reaction prevention and mitigation, and separation of sodium from chemically incompatible fluids). Because the SFR-DCs are specific to SFRs like Natrium, the NRC staff considers these PDCs to provide an acceptable basis for the Natrium PDCs. Changes to these PDCs will be discussed in SE Section 3.2.4.

The NRC staff identified that SFR-DC 70 in RG 1.232 contains an error, referring to "anticipated *occupational* occurrences" (emphasis added) rather than the intended "anticipated operational occurrences," as used elsewhere in RG 1.232. On April 10, 2024, TerraPower submitted Revision 1 to the subject topical report correcting Natrium PDC 70 to use "anticipated operational occurrences" in Table 2. Because this change addresses the error, it is acceptable to the NRC staff.

3.2.2 MHTGR-DC-derived PDCs

Several Natrium PDCs were based on the MHTGR-DCs in Appendix C to RG 1.232. Specifically, Natrium PDCs 13, 16, 20, 25, 80, 81, and 82 were derived from MHTGR-DCs 13, 16, 20, 25, 70, 71, and 72, respectively. While the Natrium design does not have much in common with the MHTGR design used to develop the criteria in Appendix C to RG 1.232, the RG states that applicants are "free to choose among the [ARDC], SFR-DC, or MHTGR-DC to develop each PDC after considering the underlying safety basis for the criterion and evaluating the rationale for the adaptation described in this RG." The NRC staff therefore considers the use of the MHTGR-DCs acceptable as the basis for establishing DC for an SFR design, provided the safety basis is appropriately preserved and the adaptations are relevant to the design.

Most of the MHTGR-DCs used as the basis for the Natrium PDCs are used either because they implement the functional containment approach (Natrium PDCs 13, 16, 81, and 82) or reflect the use of SARRDLs (Natrium PDCs 20 and 25). Since these concepts are acceptable for the Natrium design as discussed in Sections 3.1.4 and 3.1.3 of this SE, respectively, it is appropriate to use the MHTGR-DCs as the basis for the relevant Natrium PDCs. Changes to the MHTGR-DC-derived PDCs are discussed in SE Section 3.2.4.

Natrium PDC 80 is based on MHTGR-DC 70, which was added to the MHTGR-DCs to ensure passive heat removal is maintained and neutron absorbers can be sufficiently inserted. TerraPower noted that this DC was adopted without changes to support other Natrium PDC with MHTGR-derived language. The NRC staff considers the adoption of this PDC to be appropriate to ensure consistency with the other adopted MHTGR-DC and therefore finds it to be acceptable.

3.2.3 "Deleted" PDCs

TerraPower did not include a PDC 27 analogous to GDC 27, but states that the information covered by GDC 27 was incorporated into PDC 26, which is based SFR-DC 26. The NRC staff finds this acceptable because this approach is consistent with that taken in all three appendices of RG 1.232 (including for the SFR-DC), in which there is no DC 27, and the information addressing matters within the scope of GDC 27 is incorporated into DC 26.

TerraPower did not include PDCs numbered 38-43 and 50-57 (and therefore did not include SFR-DC 38-43 and 50-57); these were marked as deleted due to the adoption of the functional containment approach, consistent with the MHTGR-DCs in RG 1.232 Appendix C. The NRC staff finds this acceptable because Natrium employs a functional containment as discussed in SE Section 3.1.4.

3.2.4 Modifications from SFR- and MHTGR-DCs

As discussed above, all Natrium PDCs are based on either the SFR-DC or MHTGR-DC from RG 1.232. Natrium PDCs 11, 21-25, 29, 35, 36, 45, 60, 62, 63, 70, 71, 74, 79, and 80 were adopted from the SFR- and MHTGR-DCs with no changes.

Many Natrium PDCs were modified from the SFR- and MHTGR-DCs based on one of the generic changes discussed in SE Section 3.1. These include:

- changed to use “safety significant”: 1, 2, 3, 4, 16, 18, 20, 44, 61, 72, 73, 75, 77;
- modified to incorporate SARRDLs: 10, 12, 26, 33, 34;
- adopted graded approach to boundary quality: 13, 14, 15, 28, 30, 31, 32, 76;
- changed to use “safe shutdown”: 19;
- removal of MHTGR-specific language: 81, 82; and
- leak-tightness of cooling systems: 37, 46.

Several PDCs were modified from the SFR- and MHRTGR-DCs based on two of the generic changes discussed in SE Section 3.1. These include:

- changed to use “safety-significant” and “safe shutdown”: 5; and
- changed to use “safety-significant” and to incorporate SARRDLs: 17, 78.

These changes were all addressed generically in Section 3.1 of this SE and are considered by the NRC staff to be acceptable for the reasons previously discussed.

Only one PDC had changes not previously addressed. Natrium PDC 64, "Monitoring radioactivity releases,” was based on SFR-DC 64 which states, that “means shall be provided for monitoring the reactor containment atmosphere, spaces containing components for primary system sodium and cover gas cleanup and processing, effluent discharge paths, and the plant environs for radioactivity that may be released from normal operations, including [AOOs], and from postulated accidents.” TerraPower revised SFR-DC 64 to reflect that the reactor building atmosphere, rather than the containment, shall be monitored, consistent with the approach in MHTGR-DC 64. TerraPower stated that the purpose for using SFR-DC 64 for the base language was to reflect SFR-specific references to sodium and cover gas cleanup and processing systems, but that the change was needed to reflect the use of a functional containment approach.

The NRC staff finds the Natrium PDC 64 acceptable because it appropriately retains the important characteristics of SFR-DC 64 while incorporating changes necessary to reflect the functional containment approach.

4. Rationale for Meeting Natrium PDC 26

TerraPower requested NRC staff review of the rationale provided in the TR for meeting the intent of Natrium PDC 26. In TR Section 5.3.2, "Independent and Diverse," TerraPower indicated that there are two different control rod assembly (CRA) designs as well as two different means of inserting the CRAs into the reactor core, namely a scram latch release that allows the CRAs to be pulled into the core by gravity and a separate motor driven scram insertion function that would allow the CRAs to be pushed into the core by the control rod drive system. Additional context on TerraPower's rationale for meeting the intent of Natrium PDC 26 was also provided during a November 10, 2022, meeting with the NRC staff (ML22301A073).

As discussed in SE Section 3.2.1, Natrium PDC 26 is based on SFR-DC 26 with a change to use SARRDLs instead of SAFDLs. The PDC requires a "minimum of two reactivity control systems or means," one of which must be "independent and diverse from the others." The NRC's rationale for adaptations to the GDC for SFR-DC 26 in RG 1.232 states that "the term 'independent and diverse' indicates no shared systems or components and a design which is different enough such that no common failure modes exist" between the systems relied on for sentence (1) and (3) and the system relied on for sentence (2) of the DC. The adaptations to the GDC also state that the system relied on for sentence (2) of the DC would be considered "important to safety but not necessarily safety-related."

TerraPower stated that it intends to demonstrate that, though it may not be consistent with the rationale in RG 1.232 discussed above, the combination of different CRA designs and means of insertion on a scram signal is sufficiently diverse and independent to meet the underlying intent and requirements for reactivity control. The argument relies in part on analyses performed using the Natrium probabilistic risk assessment (PRA) which indicated that the primary issues with the CRAs are related to binding, either associated with the gripper or binding between the bundle and the duct. The secondary control rod design intends to mitigate the bundle/duct binding failure mode that would otherwise be shared with the primary control rods, while the use of the motor driven scram insertion function would mitigate gripper binding. Various tests are planned to demonstrate the capabilities of the secondary control rod design.

The NRC staff generally finds this approach to be reasonable in meeting the underlying intent of PDC 26 because it uses a robust, RIPB approach to demonstrate that there is sufficient independence, diversity, and redundancy in the reactivity control system to reliably provide reactivity control and shutdown capability for normal operation, transients, and accident scenarios.

However, the NRC staff cannot reach a final determination on whether the proposed approach meets PDC 26 because it relies on integrated evaluations that involve the Natrium plant PRA, failure mode and effects analysis of the CRAs and control rod drive system, and the safety analysis. As such, though the approach is reasonable, the NRC staff is unable to make a final determination regarding whether TerraPower has demonstrated conformance of the Natrium design with PDC 26 at this time. The NRC staff will review conformance of the Natrium design with PDC 26 as part of a separate licensing action.

5. Scope and Applicability of PDCs

As discussed in the audit report supporting this TR review (ML24051A030), TerraPower indicated that Anticipated Operational Occurrences (AOOs), as used in the proposed Natrium PDCs, are consistent with the equivalent licensing basis event category from NEI 18-04.

TerraPower also indicated that various types of accidents, including “accidents,” “postulated accidents,” and “accident conditions,” all refer to events in the design basis accident (DBA) category from NEI 18-04. The DBAs are derived from design basis events (DBEs), as discussed in NEI 18-04.

The process described in NEI 18-04 is complemented by content of application guidance provided in NEI 21-07, which is endorsed by RG 1.253. The NRC staff Position C.6.a.(2) of RG 1.253 provides a clarification noting that:

> [T]he scope of the proposed PDC should include SSCs important to safety. For applicants using the LMP process endorsed in RG 1.233, SSCs important to safety include both SR and NSRST SSCs. Therefore, the proposed PDC will need to address the functions provided by both SR and NSRST SSCs.

RG 1.233 and NEI 18-04 indicate that SR SSCs are defined in terms of their ability to mitigate the consequences of DBEs or DBAs, or to prevent the frequency of high-consequence beyond design basis events (BDBEs) from increasing into the DBE frequency range (and beyond the frequency-consequence target curve). NSRST SSCs are defined in terms of their ability to mitigate licensing basis events in any of the frequency categories, including AOOs, DBEs, or BDBEs. NSRST SSCs also include those SSCs needed for defense in depth (DID) adequacy.

As discussed above, TerraPower’s PDCs relate only to normal operation, AOOs, and DBAs. Because DBAs are derived from and represent bounding scenarios for DBEs, the NRC staff considers that the PDCs are also adequate for DBE scenarios as well. However, because BDBEs are not considered within the PDCs in the TR, there is a potential gap for those SR SSCs needed to prevent high consequence BDBEs from increasing into the DBE frequency range, if such high consequence BDBEs exist for Natrium. There are also potential gaps in the PDCs for those NSRST SSCs needed to mitigate BDBEs, and for SSCs needed for DID adequacy. Accordingly, the NRC staff imposed Limitation and Condition 2 to ensure that the scope of the Natrium PDCs in a future license application is aligned with the approach outlined in NEI 18-04, as endorsed in RG 1.233.

The NRC staff notes that NEI 21-07, Section C, Chapter 5, “Safety Functions, Design Criteria, and SSC Classification,” provides guidance on development of PDCs under the LMP process. NEI 21-07 distinguishes between PDCs (which are defined based on the required functional design criteria, or RFDC) and “complementary design criteria” (CDCs) needed for NSRST SSCs. However, RG 1.253 states that NEI 21-07 “divides PDC into PDC-RFDC and PDC-CDC,” indicating that both RFDCs and CDCs may be necessary to define a complete set of PDCs. Because the potential gaps primarily relate to NSRST SSCs, the NRC staff expects that any additional PDCs needed would be established with a minimum scope and content similar to that discussed in NEI 21-07, Section C, Section 5.6, “Principal Design Criteria - Complementary Design Criteria.”

LIMITATIONS AND CONDITIONS

The NRC staff imposes the following limitations and conditions regarding the TR:

1. An applicant or licensee referencing this TR must propose a design that is substantially similar to the Natrium design as discussed in SE Section 1, or otherwise justify that any departures from these design features do not affect the conclusions of the TR and this SE.

2. The use of this TR is restricted to those applicants using the risk-informed, performance-based licensing process described in NEI 18-04, Revision 1, as endorsed by RG 1.233. Because the proposed PDCs may not fully address all performance requirements for SSCs defined as safety-significant under the NEI 18-04 process, applicants or licensees referencing this TR must augment the PDC in the TR with appropriate PDC for any SR or NSRST SSCs whose safety function relates to BDBEs, or NSRST SSCs needed for DID adequacy, or otherwise justify that the Natrium PDCs as described in the subject TR are adequate.

CONCLUSION

Based on the above evaluation, the NRC staff concludes that TerraPower has considered each of the design aspects presented in RG 1.232 and provided a sufficient set of PDCs that are appropriate for establishing requirements for the Natrium design, subject to the limitations and conditions listed in this SE. Subject to these limitations and conditions, these PDCs establish the necessary design, fabrication, construction, testing, and performance DC for safety significant SSCs to provide reasonable assurance that the Natrium reactor could be operated without undue risk to the health and safety of the public. The subject TR is therefore suitable for referencing in future licensing applications for the Natrium advanced reactor.

Project Managers: Roel Brusselmans, NRR
Stephanie Devlin-Gill, NRR
Mallecia Sutton, NRR

Principal Contributors: Reed Anzalone, NRR