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DRAFT SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

LICENSING TOPICAL REPORT NEDC-33926P, REVISION 2

BWRX-300 STEEL-PLATE COMPOSITE CONTAINMENT VESSEL AND REACTOR BUILDING STRUCTURAL DESIGN

GE-HITACHI NUCLEAR ENERGY AMERICAS, LLC

DOCKET NO. 99900003

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1.0 INTRODUCTION

GE-Hitachi Nuclear Energy Americas, LLC (GEH), submitted Licensing Topical Report (LTR) NEDC-33926P/NEDC-33926, Revision 0, "BWRX-300 Steel-Plate Composite (SC) Containment Vessel (SCCV) and Reactor Building (RB) Structural Design (proprietary/non-proprietary)," by letter dated May 4, 2023 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML23124A405 (Package), ML23124A406 (Letter); ML23124A407 (proprietary) ML23124A408 (non-proprietary)). By letter dated July 31, 2023 (ML23212B127), GEH submitted supplemental information to support the U.S. Nuclear Regulatory Commission (NRC) acceptance of the LTR for review. Further, by letter dated August 18, 2023 (ML23230B212 (Package), ML23230B213 (Letter)), GEH submitted LTR NEDC-33926P/ NEDC-33926, Revision 1 (ML23230B214 (proprietary), ML23230B215 (non-proprietary)), reclassifying select content as non-proprietary. The NRC staff reviewed the LTR and the supplemental information with respect to the provisions proposed by GEH for the structural design approach and methodology of the SCCV and RB, using steel-plate composite modules with diaphragm plates (DP-SC), for the BWRX-300 small modular reactor (SMR).

In this safety evaluation (SE), the NRC staff documents its review of the acceptability of the LTR proposed approach and methodology for the structural design and construction of the BWRX-300 SCCV and RB using DP-SC modules. During the review, an audit was held to seek clarification, gain understanding, and verify information related to the subject LTR. The public audit plan (ML23254A064) was issued September 12, 2023, and the audit summary report (ML24103A004) was issued June 21, 2024. In response to the NRC staff's requests for additional information (RAIs), GEH submitted responses by letters dated February 12, 2024 ML24044A256 (package), ML24044A257 (letter)); ML24044A258 (proprietary); ML24044A259 and ML24044A260 (both non-proprietary)) and March 14, 2024 (ML24094A292 (package), ML24094A293 (letter)); ML24094A294 (proprietary); ML24094A295 (non-proprietary)). Further, by letter dated April 18, 2024 (ML24110A131 (package), ML24110A132 (letter)), GEH submitted LTR NEDC-33926P/ NEDC-33926, Revision 2 (ML24110A133 (proprietary), ML24110A134 (non-proprietary)), hereafter referred to as LTR, incorporating changes that resulted from regulatory audit questions and responses to RAIs. This SE is based on Revision 2 of the LTR NEDC-33926P. The NRC staff will evaluate the compliance of the structural design of the DP-SC SCCV and RB structures for the BWRX-300 SMR during future licensing activities in accordance with Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities," or Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants," as applicable with the Limitations and Conditions (L&Cs) as outlined in Section 8.0 of this SE.

1.1 Purpose

GEH in its LTR requested NRC approval of a proposed structural design approach and methodology for the BWRX-300 integrated Reactor Building (RB) consisting of the use of DP-SC modules for the Containment Vessel (SCCV), the reactor pressure vessel (RPV) pedestal part of containment internal structures, and the RB structural elements.

Current design codes do not address the use of SC structural systems as a containment pressure boundary and do not address the use of DP-SC for any structure including containment. Therefore, GEH proposed specific design rules for the SCCV by adapting the content structure and provisions of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (BPVC), 2021 Edition, Section III, Rules for Construction of Nuclear Facility Components, Division 2, Code for Concrete Containments, Subsection CC, Concrete Containments, Articles CC-1000 through CC-6000, for materials, design, fabrication and construction, construction testing and examination, and structural integrity testing for the BWRX-300 SCCV, including Division 2 Appendices to the extent they apply to an SC containment without reinforcing steel or tendons, and further supplemented/augmented it with research literature and modified criteria from American Institute of Steel Construction (AISC)/American National Standards Institute (ANSI) N690-18. In addition, GEH proposed in the LTR specific structural design rules for the RB and the containment internal structures not part of the SCCV pressure boundary (i.e., RPV pedestal) based on current codes and standards (i.e., AISC N690-18, Chapters NM, NN and Appendix N9) with some proposed modified criteria to cover design elements that are beyond the scope of current codes and standards. GEH stated the proposed design rules in the LTR for the RB and the RPV pedestal structure and SCCV DP-SC modules is further confirmed and supplemented by a test program performed under Phase 1 of the National Reactor Innovation Center (NRIC) Advanced Construction Technology project in the United States. This program is known as the BWRX-300 NRIC Demonstration Program.

The LTR describes the approach and technical bases for meeting applicable regulatory requirements by adapting, to the extent applicable, cognizant existing codes and standards which are further supplemented and modified by design rules that are specific to the BWRX-300 SC structures for the design of the integrated RB and the pressure-retaining SCCV using DP-SC technology, confirmed by the NRIC prototype testing program results that demonstrate and validate the safety margins of the DP-SC structural design approach / methodology proposed for the BWRX-300 SMR.

The stated purpose of this LTR includes the following requests to demonstrate compliance with the safety and performance objectives of established regulatory requirements:

- The NRC approval of the design approach and methodology of DP-SC structural elements for the GEH BWRX-300 seismic Category I containment and RB structures.

- The NRC approval of the requirements for the fabrication, construction, testing, and examination of DP-SC structural elements for the GEH BWRX-300 containment and RB structures.

- The NRC design-specific approval for the use of:
    - Proposed criteria and requirements for materials, design, fabrication, construction, examination, and testing for the BWRX-300 SCCV adapted from the ASME BPVC 2021 Edition, Section III, “Rules for Construction of Nuclear Facility Components,” Division 2, “Code for Concrete Containments,” Subsection CC, “Concrete Containments,” Articles CC-1000 through CC-6000, including Division 2 Appendices (LTR Reference 9-1).

    - Modified criteria and requirements to ANSI/ AISC N690-18 (LTR Reference 9-2), Chapters NM, NN, and Appendix N9 for design, analysis, fabrication, construction, examination, and testing of BWRX-300 non-containment seismic Category I structural members, including slabs and curved walls, built using DP-SC modules.

1.2 <u>Implementation</u>

An applicant who references a topical report in a licensing application must demonstrate that the application of the topical report to their specific facility is within the scope of the conditions in the topical report defining its application. The NRC staff verifies relevant criteria for accepted-for-use topical reports during each licensing action to ensure that the topical report's conclusions are both valid and applicable to the specific licensing action under review. This LTR is a BWRX-300 design-specific methodology that would be applicable to NRC licensing under 10 CFR Part 50.

Accordingly, upon implementation of this LTR into a site-specific application of the BWRX-300 design, the staff will evaluate each topical area designated below in SE Section 1.3 to ensure that each topic appropriately interfaces with the proposed license application to ensure consistency with what the staff approved. The staff will also make its regulatory determinations regarding the topics discussed below, as applicable, during its review of any future license application.

1.3 <u>Scope of the NRC Staff’s Review and Approval</u>

The scope of the NRC staff review of this LTR includes the following:

- Regulatory evaluation of compliance of the applicant’s proposed design rules for the BWRX-300 DP-SC structural modules to the applicable NRC regulations, and conformance to the associated regulatory review guidance of NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR

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Edition," the Standard Review Plan (SRP), and regulatory guides (RGs) associated with the proposed BWRX-300 SCCV and RB Structural Design addressed in LTR Sections 2.1, 2.2 and 2.3, respectively.

- Technical evaluation of overall structural analysis and design approach of BWRX-300 DP-SC integrated RB, including analysis method, modeling, design loads and load combinations, and design codes/proposed criteria/methodology jurisdictions and supporting technical bases described and illustrated in LTR Section 4.0.

- Technical evaluation of proposed modified criteria, requirements, and supporting technical bases, addressed in LTR Chapter 5.0, to ANSI/AISC N690-18, Chapters NM, NN, and Appendix N9 for design, analysis, fabrication, construction, examination, and testing of BWRX-300 non-containment seismic Category I structural members, including slabs and curved walls, built using DP-SC modules. This includes additional technical bases necessary for DP-SC modules including results of the confirmatory NRIC test program summarized in LTR Section 7.0.

- Technical evaluation of proposed criteria and requirements and supporting technical bases, addressed in LTR Chapter 6.0, for materials, design, fabrication, construction, examination, and testing for the BWRX-300 SCCV adapted as applicable from the ASME BPVC 2021 Edition, Section III, Division 2, Subsection CC, Articles CC-1000 through CC-6000, including Division 2 Appendices (Reference 9-1) and modified/supplemented by additional technical bases necessary for DP-SC including results of NRIC test program summarized in LTR Section 7.0.

- Summary evaluation of the NRIC Demonstration Program Phase 1 Prototype test conclusions, described in LTR Section 7.0 that is confirmatory of the proposed design approaches discussed in LTR Sections 5.0 and 6.0.

1.4 <u>Description of the BWRX-300 SMR</u>

As described in LTR Section 3.2, the BWRX-300 is a water-cooled, natural circulation-driven SMR with a power output of about 300 megawatts electric. GEH describes the BWRX-300 as the tenth generation of the boiling-water reactor (BWR) that has evolved from the Economic Simplified Boiling-Water Reactor, certified by the NRC in 2014. GEH stated that the BWRX-300 containment design is based on GEH BWR experience and fleet performance and includes features such as a size comparable to a small BWR drywell, accident pressure and temperatures within existing BWRs, nitrogen-inerted same as previous BWRs, and heat removal upon loss of active cooling achieved by the passive containment cooling system.

The BWRX-300 RPV, SCCV, and other safety-related structures, systems, and components (SSCs) including the fuel pool are located within and protected by the deeply embedded RB. The RB is placed in a vertical right-cylinder shaft, the majority of which is located below-grade to mitigate effects of possible external events, including aircraft crashes, adverse weather, flooding, fires, and earthquakes. The walls, floors, roof, and mat foundation of the RB structure are primarily constructed using DP-SC modules. The below-grade portion of the RB houses the containment and containment internal structures as well as RPV and safety systems. The SCCV portion of the containment consists of a cylindrical wall, mat foundation and top slab constructed using DP-SC modules. The metal containment closure head and other metal components (hatches, penetrations) not backed by concrete at the pressure boundary are ASME Class MC components. The SCCV houses the containment internal structures which includes the DP-SC RPV pedestal, traditional SC bioshield, and steel support structures. The RB, SCCV and containment internal structures are integrated at the DP-SC mat foundation as well as at the wing walls and floor slabs.

2.0 REGULATORY BASIS AND EVALUATION

2.1 <u>Regulatory Requirements</u>

In the LTR, GEH proposed structural design rules/criteria for the BWRX-300 RB structures and components including the fuel pool, containment structure (SCCV), and the RPV pedestal (a containment internal structure) for the first-time use of DP-SC structural modules to meet the applicable NRC regulatory requirements of:

- 10 CFR Part 50, Appendix A, “General Design Criteria (GDC) for Nuclear Power Plants.” Specifically, requirements of GDC 1, “Quality standards and records,” and GDC 2, “Design bases for protection against natural phenomena,” GDC 4, “Environmental and dynamic effects design bases,” and additionally for SCCV only, GDC 16, “Containment design,” GDC 50, “Containment design basis,” GDC 51, “Fracture prevention of containment pressure boundary,” GDC 52, “Capability for containment leakage rate testing,” and GDC 53, “Provisions for containment testing and inspection.”

- 10 CFR Part 50, Appendix B, “Quality assurance criteria for nuclear power plants,” which requires, to include in its preliminary safety analysis report a description of the quality assurance (QA) program to be applied to the design, fabrication, construction, and testing of the safety-related SSCs of the facility.

- 10 CFR Part 50, Appendix J, “Primary reactor containment leakage testing for water-cooled power reactors,” which requires that primary reactor containments shall meet the containment leakage test requirements set forth in this appendix. These test requirements provide for pre-operational and periodic verification by tests of the leak-tight integrity of the primary reactor containment, and systems and components which penetrate containment of water-cooled power reactors and establish the acceptance criteria for these tests.

- 10 CFR Part 50, Appendix S, “Earthquake engineering criteria for nuclear power plants,” to meet GDC 2 for earthquakes, requires that for safe shutdown earthquake (SSE) ground motions in combination with effects of normal operating and accident-induced loads, safety-related SSCs (including integrated RB structures and components, and SCCV) to remain functional during and after the SSE within applicable stress, strain, and deformation limits. The required safety functions of SSCs must be assured during and after the vibratory ground motion through design, testing, or qualification methods. The evaluation must account for soil-structure interaction (SSI) effects and the expected duration of vibratory motion. This regulation also requires that when the Operating Basis Earthquake (OBE) is set at greater than one-third the SSE ground motion design response spectra, all SSCs necessary for continued operation without undue risk to public health and safety must remain functional and within applicable stress, strain, and

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deformation limits under the effects of OBE ground motion in combination with normal operating loads.

- 10 CFR 50.34(f), "Additional TMI-related requirements," specifically §50.34(f)(3)(v)(A) and (B) require that containment structures meet specific provisions of the ASME BPVC Section III, Division 1 (for steel containments) or Division 2 (for concrete containments) when subjected to loads resulting from fuel damage, fuel clad metal-water reactions, hydrogen burning, and inerting system actuations.

  §50.34(f)(v)(A)(1) requires an applicant to demonstrate that containment integrity will be maintained, which for concrete containments is done by meeting the requirements of ASME Code, Section III, Division 2, Subarticle CC-3720, Factored Load Category, considering pressure and dead load alone, during an accident that releases hydrogen generated from 100 percent fuel clad metal-water reaction accompanied by either hydrogen burning or the added pressure from post-accident inerting assuming carbon dioxide is the inerting agent. As a minimum, the specific code requirements set forth above appropriate for each type of containment will be met for a combination of dead load and an internal pressure of 45 psig.

- 10 CFR 50.44, "Combustible gas control for nuclear power reactors," provides the requirements for combustible gas control for reactors. Specifically, for future water-cooled reactor applicants and licensees, §50.44(c)(5) "Structural analysis," requires that an applicant must perform an analysis using an NRC-accepted analytical technique that demonstrates containment structural integrity under an accident that releases hydrogen generated from 100 percent fuel clad-coolant reaction accompanied by hydrogen burning.

- 10 CFR 50.55a "Codes and Standards," specifically §50.55a(g)(4) requires inservice inspection (ISI) of pressure-retaining components and integral attachments of Class MC containments and pressure-retaining concrete components and metallic shell and penetration liners of Class CC containments shall be performed in accordance with the applicable edition of the ASME BPVC, Section XI, Division 1, "Rules for Inspection and Testing of Components of Light Water Cooled Plants," Subsection IWE and Subsection IWL, as incorporated by reference and subject to conditions stated in this regulation.

- 10 CFR 50.65, "Requirements for monitoring the effectiveness of maintenance at nuclear power plants," paragraph (a)(1), requires each holder of an operating license for a nuclear power plant to monitor the performance or condition of structures, systems, or components important to safety, against licensee-established goals, in a manner sufficient to provide reasonable assurance that these SSCs are capable of performing their intended functions. These goals shall be established commensurate with safety and, where practical, account for industrywide operating experience. When the performance or condition of an SSC does not meet established goals, appropriate corrective action shall be taken.

- 10 CFR 50.150, "Aircraft impact assessment," requires each applicant to perform a design-specific assessment of the effects on the facility of the impact of beyond-design-basis large commercial aircraft using realistic analyses to identify and incorporate design features and functional capabilities to show that (i) the reactor core remains cooled or the containment remains intact, and (ii) spent fuel cooling or spent fuel integrity is maintained.

This LTR describes the applicant's intent to meet the above regulatory requirements for the BWRX-300 integrated RB structures. LTR Section 2.1 identifies and describes each of the specific 10 CFR Part 50 regulations that GEH determined to be applicable to the materials, design, fabrication, construction, examination, and testing (hereafter referred to as structural design and construction) using DP-SC modules for the integrated RB, which includes the RB structures and components including the fuel pool, the SCCV and RPV pedestal. LTR Section 2.1 also provides statements of compliance, by referencing the technical approach in one or more specific subsections of LTR Sections 4.0, 5.0, 6.0, 7.0 and/or RG, thereby indicating how the proposed BWRX-300 design will meet the requirements of each of the applicable regulations.

Based on its technical evaluations in the SE, the NRC staff finds that the methodology/approaches and technical bases described by GEH in LTR Sections 4.0 through 7.0 to meet the applicable regulations are reasonable. The NRC staff will conduct a detailed evaluation to confirm the 10 CFR Part 50 regulatory requirements are met/satisfied for the specific final plant design when an application for a BWRX-300 SMR is received.

Since the LTR proposed a methodology and supporting technical bases for use of DP-SC technology by adapting, supplementing, and modifying existing codes and standards, namely, ASME Section III, Division 2 for SCCV and ANSI/AISC N690-18, the NRC staff notes that its review of the LTR as an acceptable way of complying with the above regulations involved, among others, specific focus on GDC 1, "Quality Standards and Records." This regulation requires, in part, that where generally recognized codes and standards are used, they shall be identified and evaluated for applicability, adequacy, and sufficiency and shall be supplemented or modified as necessary to assure a quality product in keeping with the required safety function.

2.2 NUREG-0800 Standard Review Plan Guidance

The NRC staff review guidance in the following sections of NUREG-0800 are identified to be applicable to the review of the DP-SC modular construction technology proposed in the LTR.

- SRP Section 3.5.3, "Barrier Design Procedures," provides guidance in the design of seismic Category I structures, shields, and barriers to withstand the effects of missile impact to ensure conformance with 10 CFR Part 50, GDC 2 and 4.

- SRP Section 3.8.1, "Concrete Containment," provides guidance for materials, loads and load combinations, design and analysis procedures, construction, examination, and testing related to concrete containments or to concrete portions of steel/concrete containments.

- SRP Section 3.8.2, "Steel Containment," provides guidance related to steel containments or other Class MC components of steel/concrete containments. Since Class MC components interfacing the DP-SC SCCV are outside the scope of the LTR, SRP Section 3.8.2 is not directly applicable to the LTR.

- SRP Section 3.8.3, “Concrete and Steel Internal Structures of Steel or Concrete Containments,” provides guidance for materials, structural analysis, design and construction and examination, for containment internal structures, including case-by-case review of modular construction methods. This guidance applies to the BWRX-300 DP-SC RPV pedestal which supports the reactor vessel.

- SRP Section 3.8.4, “Other Seismic Category I Structures,” provides guidance for materials, structural analysis and design and construction of other seismic Category I structures (i.e., other than containment and its interior structures). This includes specific areas of review that are applicable to the RB structure surrounding the containment, including fuel pools.

- SRP Section 3.8.5, “Foundations,” provides guidance relating to the foundations of all seismic Category I structures.

- SRP Section 19.5, “Adequacy of Design Features and Functional Capabilities Identified and Described for Withstanding Aircraft Impacts,” provides guidance to perform a design-specific assessment required by 10 CFR 50.150 of the effects on the facility of the impact of a large commercial aircraft.

- SRP Section 19.0, “Probabilistic Risk Assessment and Severe Accident Evaluation for Reactors,” SRP Section 19.0, “Probabilistic Risk Assessment (PRA) and Severe Accident Evaluation for New Reactors,” provides review guidance of the applicant’s design-specific PRA and evaluation of design features for prevention or mitigation of severe accidents. The structural performance of the containment under severe accident loads reviewed by the staff encompasses: (1) the applicant’s assessment of the Level C (or factored load) pressure capability of the containment in accordance with 10 CFR 50.44(c)(5); (2) the applicant’s demonstration of the containment capability to withstand the pressure and temperature loads induced by the more likely severe accident scenarios as stipulated in SECY-93-087, “Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced Light Water Reactor Designs,” Section I.J; (3) the applicant’s containment structural fragility assessment for over-pressurization; and (4) the applicant’s assessment of the seismic capacity of the containment structure in meeting the expectation documented in SECY-93-087, Section II.N

In its response to Question 1 (RAI 2.1.2-1) by letter, dated February 12, 2024, GEH clarified that compliance with the Commission’s Severe Accident Performance Goal for containment structures stipulated in SECY-93-087, (ML003708021) and related staff requirements memorandum (SRM) (ML003708056), specifically plant-specific PRA and severe accident evaluations that will demonstrate survivability of the containment and its robustness against the four criteria in SRP Section 19.0, including seismic margins assessment, will be addressed in Chapter 19 and Section 15.6 of the plant-specific Final Safety Analysis Report (FSAR). Therefore, the NRC staff considers this aspect *outside of the LTR scope*. However, the statement of conformance to SRP Section 19.0 in LTR Section 2.2.7 states, in part: “The BWRX-300 containment structural performance under beyond design-basis and severe accident loads related to containment ultimate pressure capacity, combustible gas pressure loads, and ability to maintain leak-tight barrier following the onset of core damage is evaluated following the regulatory guidance of SRP Section19.0, [using approach] as described in LTR Section 6.23.” Therefore, the NRC staff notes that the methodology/approach that will be used to perform

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these evaluations are in the scope of the LTR as described in LTR Sections 6.23.1, 6.23.2. and 6.23.3, respectively. ***[L&C 8.1(i)]***

In LTR Section 2.2, GEH identified each of the above SRP guidance as applicable to the BWRX-300 DP-SC Integrated RB and SCCV design and construction approach and provided a statement of conformance. The NRC staff finds GEH's general approach and extent of conforming with each of the above applicable SRP guidance generally consistent with the review guidance to the extent applicable to DP-SC, and therefore reasonable. The NRC staff will conduct a detailed review to confirm whether the BWRX-300 DP-SC integrated RB and SCCV conforms to the identified SRP guidance, as applicable, as intended in the LTR when an application for a BWRX-300 SMR is received.

2.3 Nuclear Regulatory Commission Regulatory Guides

Applicable RGs used by the NRC staff to ensure compliance to applicable NRC regulations include:

- RG 1.7, "Control of Combustible Gas Concentrations in Containment Following a Loss of Coolant Accident," describes methods acceptable to the NRC staff for implementing the regulatory requirements of 10 CFR 50.44 for reactors subject to the provisions of Sections 50.44(b) or 50.44(c) with regard to control of combustible gases generated by beyond design-basis Accident (DBA) that could be a risk significant threat to containment integrity. For applicants and holders of a water-cooled reactor CP or operating license under 10 CFR Part 50 that are docketed after October 16, 2003, containments must have an inerted atmosphere or limit combustible gas concentrations in containment during and following an accident that releases an equivalent of combustible gas as would be generated from a 100 percent fuel clad coolant reaction, uniformly distributed, to less than 10 percent (by volume) and must maintain containment structural integrity.

- RG 1.26, "Quality Group Classifications and Standards for Water, Steam, and Radioactive Waste Containing Components of Nuclear Power Plants," describes methods acceptable to the NRC staff for use in implementing the regulatory requirements of 10 CFR Part 50, Appendix A, GDC 1, "Quality Standards and Records," with regard to a quality classification system related to specified national standards that may be used to determine quality standards acceptable to the NRC staff for components containing water, steam, or radioactive material in light water cooled nuclear power plants.

- RG 1.28, "Quality Assurance Program Criteria (Design and Construction)," for addressing 10 CFR Part 50, Appendix B QA requirements, as it applies to the RB and SCCV, describes methods that the staff of the NRC considers acceptable for complying with the provisions of 10 CFR Part 50, Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants," for establishing and implementing a QA program for the design and construction of nuclear power plants and fuel reprocessing plants. 10 CFR Part 50, Appendix A, GDC 1 and 10 CFR 50.34(a)(7) provide a description of the QA program to be applied to the design, fabrication, construction, and testing of the SSCs of the facility, and a discussion of how the applicable requirements of Appendix B to 10 CFR Part 50, Appendix B, will be satisfied.

- RG 1.54, “Service Level I, II, III and In-Scope License Renewal Protective Coatings Applied to Nuclear Power Plants” (Reference 9-25), describes a method that the staff of the NRC considers acceptable for complying with NRC requirements for the selection, application, qualification, inspection, and maintenance of protective coatings applied to nuclear power plants. 10 CFR Part 50, Appendix A, GDC 1 and 4, Appendix B, and 10 CFR 50.65 are applicable regulations for NRC RG 1.54.

- RG 1.57, “Design Limits and Loading Combinations for Metal Primary Reactor Containment System Components,” describes an approach that the NRC staff considers acceptable for use in satisfying the requirements of General Design Criteria 1, 2, 4, and 16, as specified in 10 CFR Part 50, Appendix A, “General Design Criteria for Nuclear Power Plants.” The leak tightness of the containment structure must be tested at regular intervals during the life of the plant, in accordance with the provisions of 10 CFR Part 50, Appendix J, “Primary Reactor Containment Leakage Testing for Water-Cooled Power Reactors.” In addition, for certain reactors specified in 10 CFR 50.34(f), 10 CFR 50.34(f)(3)(v)(A) and (B) require steel containments to meet specific provisions of the ASME BPVC when subjected to loads resulting from fuel damage, metal-water reactions, hydrogen burning, and inerting system actuations.

- RG 1.61, “Damping Values for Seismic Design of Nuclear Power Plants,” Revision 2, describes acceptable damping values, including for SC modules, that the NRC staff can use in reviewing the seismic response analysis of seismic Category I nuclear power plant SSCs in accordance with 10 CFR Part 50, GDC 2, which requires that SSCs important to safety be designed to withstand the effects of natural phenomena such as earthquakes, in combination with appropriate normal and accident loads, without losing the ability to perform their safety functions. 10 CFR Part 50, Appendix S, specifies the requirements for the implementation of GDC 2 with respect to earthquakes.

- RG 1.136, “Materials, Construction, and Testing of Concrete Containments,” describes an approach that is acceptable to the NRC staff to meet regulatory requirements for materials, design, construction, fabrication, examination, and testing of concrete (reinforced or prestressed) containments in nuclear power plants. 10 CFR Part 50, Appendix A, provides minimum requirements for the principal design criteria that establish the necessary design, fabrication, construction, testing, and performance requirements for SSCs important to safety to provide reasonable assurance that the facility can be operated without undue risk to the health and safety of the public. GDC 1, 2, 4, 16, and 50 are applicable to NRC RG 1.136.

The staff notes that the statement of conformance for RG 1.136 in LTR Section 2.3.7 states, in part: “… The safety and performance objectives of the regulatory guidance of U.S. NRC RG 1.136 for materials, design, construction, fabrication, examination, and testing of concrete containments are met by following the SCCV design approach provided in Section 6.0.”

The staff finds this conformance acceptable because RG 1.136 endorses with conditions the 2019 Edition of ASME Code, Section III, Division 2 “Code for Concrete

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Containments," which is a recognized existing code endorsed by the NRC, the 2021 Edition of which GEH is appropriately adapting to the extent applicable to a containment without reinforcement and tendons, and further modified and supplemented in this LTR for the DP-SC SCCV.

- RG 1.160, "Monitoring the Effectiveness of Maintenance at Nuclear Power Plants," describes methods that are acceptable to NRC staff for demonstrating compliance with the provisions of Section 50.65, "Requirements for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants," of 10 CFR Part 50. 10 CFR 50.34(b)(6)(iv) requires an operating license to include a final safety analysis report that includes plans for conduct of normal operations, including maintenance, surveillance, and periodic testing of SSCs.

- RG 1.163, "Performance-Based Containment Leak-Test Program," provides guidance on an acceptable performance-based leak-test program and leakage rate test methods, procedures, and analyses for demonstrating compliance with "Option B – Performance-Based Requirements" in Appendix J, "Primary Reactor Containment Leakage Testing for Water-Cooled Power Plants," of 10 CFR Part 50.

- RG 1.199, "Anchoring Components and Structural Supports in Concrete," describes a method acceptable to the NRC staff for compliance with regulations for the design, installation, testing, evaluation, and QA of anchors (steel embedment's) used for component and structural supports in concrete. 10 CFR Part 50, Appendix A, GDC 1, 2, and 4; 10 CFR Part 50, Appendix B; and 10 CFR Part 50, Appendix S, are applicable.

- RG 1.216, "Containment Structural Integrity Evaluation for Internal Pressure Loadings Above Design Basis Pressure," describes the methods that the NRC staff considers acceptable for: (1) predicting the internal pressure capacity for containment structures above the DBA pressure; (2) demonstrating containment structural integrity related to combustible gas control; and (3) demonstrating containment structural integrity through an analysis that specifically addresses the Commission's performance goals related to the prevention and mitigation of severe accidents. 10 CFR Part 50, Appendix A, GDC 50, "Containment Design Basis," requires that the reactor containment structure and its internal compartments can accommodate, without exceeding the design leakage rate and with sufficient margin, the calculated pressure and temperature conditions caused by a LOCA.

- RG 1.217, "Guidance for the Assessment of Beyond-Design-Basis Aircraft Impacts for Aircraft Impact Assessment," describes a method that the NRC staff considers acceptable regarding the consideration of aircraft impacts for new nuclear power reactors. In particular, this RG endorses the methodologies described in the industry guidance document, Nuclear Energy Institute (NEI) 07-13, "Methodology for Performing Aircraft Impact Assessments for New Plant Designs," Revision 8, dated April 2011.

  The NRC staff notes that the statement of conformance to SRP Section 19.5 and RG 1.217 in LTR Sections 2.2.8 and 2.3.11, respectively, states that the BWRX-300 design will apply the methodology in NEI 07-13, endorsed in RG 1.217, to perform the aircraft impact assessment to demonstrate that the acceptance criteria of 10 CFR

50.150 is met. Nevertheless, GEH also stated in LTR Section 2.2.8 and 2.3.11 that specific requirements and approaches for aircraft impact explicit dynamic analyses are not in the scope of the LTR. Therefore, the staff finds that while the BWRX-300 design will use applicable NRC guidance to demonstrate meeting the requirements of 10 CFR 50.150, specific requirements and approaches for aircraft impact explicit dynamic analyses are outside the scope of the LTR. ***[L&C 8.1(g)]***

- RG 1.243, "Safety-Related Steel Structures and Steel-Plate Composite Walls for Other Than Reactor Vessels and Containments," describes a method acceptable to the NRC staff for compliance with regulations for the design, fabrication, and erection of safety-related steel structures and SC walls for other than reactor vessels and containments. 10 CFR Part 50, Appendix A, GDC 1, 2, and 4; 10 CFR Part 50, Appendix B; and 10 CFR Part 50, Appendix S, are applicable. This guide endorses, with exceptions and clarifications, the procedures, and standards of the ANSI/AISC N690-18 code, which includes provisions for SC walls in Appendix N9.

  The staff notes that the statement of conformance to RG 1.243 in LTR Section 2.3.12 states: "The analysis, design, fabrication, construction, inspection, examination and testing of the non-containment seismic Category 1 DP-SC structures discussed in LTR Section 5.0 of the report follow the guidance of NRC RG 1.243." The staff finds this acceptable because RG 1.243 endorses with conditions the only existing standard that addresses provisions for SC Walls which are used or adapted and modified and supplemented in this LTR.

In LTR Section 2.3, GEH identified each of the above RGs as applicable to the BWRX-300 DP-SC Integrated RB and SCCV design and construction approach and provided a statement of conformance. The NRC staff finds GEH's approach and extent of conforming with each of the above applicable RGs is generally consistent with the RG guidance to the extent applicable to DP-SC, and therefore acceptable. The NRC staff will conduct a detailed evaluation to confirm whether the BWRX-300 DP-SC integrated RB and SCCV conforms to the guidance of the identified RGs, as applicable and intended in the LTR, when an application for a BWRX-300 SMR is received.

The NRC staff notes that LTR Sections 2.4, "CNSC Regulatory Requirements and Guidance," and 2.5, "Canadian Codes and Standards," address compliance with Canadian regulatory requirements, guidance and codes and standards, which is reviewed under the jurisdiction of the Canadian Nuclear Safety Commission (CNSC). Therefore, LTR Sections 2.4 and 2.5 are outside of the scope of NRC review. ***[L&C 8.1(c)]***

3.0 TECHNICAL EVALUATION: DESCRIPTION OF THE BWRX-300 INTEGRATED REACTOR BUILDING

3.1 <u>BWRX-300 Integrated Reactor Building Structures Overview</u>

The NRC staff reviewed LTR Section 3.0, "Description of the BWRX-300 Integrated Reactor Building," and noted that the Integrated RB, a deeply embedded cylindrical structure, is the only BWRX-300 seismic Category 1 structure and consists of: (1) the RB structure enclosing the containment, (2) the SCCV structure, (3) Class MC containment components including the closure head, hatches, and penetrations, and (4) the containment internal structures.

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The NRC staff review of the LTR is based on the integrated RB configuration described in LTR Section 3.3 and illustrated in LTR Figure 3-3, “Three-Dimensional Depiction of the Integrated Reactor Building,” (proprietary) and Figure 3-4, “Section View of Integrated Reactor Building,” and Figure 4-1, “BWRX-300 Integrated Reactor Building Design Codes Jurisdiction.” The scope of this LTR is limited to the following structural elements/components of the integrated RB that will be designed and constructed using DP-SC modules to the structural analysis and design approach/methodology proposed in LTR Chapters 4.0, 5.0, and 6.0:

- RB structure walls (including wing walls and fuel pool walls), floors, roof, and common mat foundation

- SCCV portion of containment consisting of cylindrical wall, common mat foundation and top slab

- The cylindrical RPV support pedestal structure of containment internal structures

- Rigid or semi-rigid connections of SC floor slabs to RB exterior wall and SCCV wall; and between wing walls and RB SC floor slabs

The LTR states that metal or structural steel components of the integrated RB, designed and constructed of steel using existing codes and standards (i.e., ASME Section III, Division 1 Class MC, and/or AISC N690-18), are outside the scope of this LTR. Therefore, Class MC closure head and other metal components of the SCCV not backed by concrete such as personnel/equipment/access hatches, mechanical and electrical penetrations; the containment equipment and piping support structure (CEPSS), the bioshield wall, and other structural steel elements of the containment internal structures are outside the LTR scope. ***[L&C 8.1(d) & (e)]***

The RB, containment (SCCV), and containment internal structures are integrated at the DP-SC common basemat foundation. The RB and SCCV structures are also integrated at the wing walls and floor slabs, including the pool slab and walls. Floor slabs that integrate the RB exterior wall and SCCV are connected using either rigid or semi-rigid connections.

The NRC staff finds that LTR Sections 3.1 through 3.3 provide an adequate description and illustration of the Integrated RB structures and identifying the DP-SC structures and components to facilitate regulatory review of the LTR scope.

3.2 Diaphragm Plate Steel-Plate Composite (DP-SC) Structures

As described in LTR Section 3.4, “Steel-Plate Composite (SC) Structures,” DP-SC structural modules are constructed by placing concrete (normal or self-consolidating) between two steel faceplates that serve as main reinforcement and permanent formwork. Steel ties, in the form of continuous diaphragm plates with holes to allow concrete flow, and steel headed stud anchors are used to develop composite action between the concrete and the steel faceplates and to maintain strain compatibility between concrete and steel. The headed stud anchors are used in addition to ties to anchor the faceplates to the concrete infill and control faceplate local buckling.

As described in the Commentary to ANSI/AISC N690-18 standard:

> "SC walls are plate or shell-type structures; they are typically not part of frame structures. In SC construction, concrete walls are reinforced with faceplates anchored to concrete using steel anchors and connected to each other using steel ties. The behavior of SC walls under axial tension, axial compression, flexure, and out-of-plane shear is comparable to that of reinforced concrete walls. However, behavior under in-plane shear, combined in-plane forces and out-of-plane moments, and thermal conditions can be significantly different from that of reinforced concrete walls. Additionally, some SC-specific limit states such as faceplate local buckling, interfacial shear failure, section delamination, etc., have to be addressed with adequate detailing of the SC wall section."

The NRC staff noted that the difference between conventional (traditional) SC modules (addressed in ANSI/AISC N690-18 - Appendix N9 and used in the AP-1000 shield building) and DP-SC modules (addressed by this LTR) is the configuration of the steel ties used to connect (by welding) the two faceplates to provide composite action, serve as out-of-plane shear reinforcement, and prevent delamination. It should be noted that conventional SC modules use discrete tie bars of round or rectangular cross-section, whereas DP-SC modules use continuous diaphragm plates with holes. Further, in conventional SC, welding of tie bars is a manual time-consuming process. Whereas in DP-SC construction, the welding process for diaphragm plates can be automated. DP-SC modules can also be used in floor construction by providing additional holes on the top faceplate to allow concrete infill that can be later sealed.

The LTR states that DP-SC modules can be built by welding a series of components fabricated as illustrated in LTR Figures 3-5(b) and 3-6 (both proprietary). The different configurations of these modules can be:

- Type A - Multi-web components (straight or curved faceplates are connected by multiple diaphragm plates)

- Type B - Single web I-shape components (built-up or hot-rolled I-beams having web holes, or castellated and cellular beams)

- Type C - Single web U-shape components (steel channels having web holes, or SteelBricks™ where a steel-plate is first profiled and then bent into an L shape, after which the L-shaped elements are welded to each other to make U-shaped bricks)

The LTR also states that a DP-SC module system consists of multiple components arranged and welded together to form a fabricated module. The DP-SC modules are spliced together to form structural walls, floors, or mat foundation sections. The DP-SC faceplates can be straight or curved in the multi-web DP-SC modules. For straight modules, the diaphragm plates are welded directly to the planar faceplates per the design configuration. For curved modules, faceplates are rolled first, then the diaphragm plates welded to the curved faceplates to create a curved multi-web DP-SC subassembly.

The LTR further states that for all DP-SC configurations (indicated in LTR Figures 3-5(b) and 3-6), the stiffness depends on the faceplates and the concrete infill. The steel faceplates and diaphragm plates contribute to the out-of-plane flexural capacity, whereas only the diaphragm plates develop the out-of-plane shear capacity. The in-plane shear capacity is developed by the steel faceplates. The diaphragm plates are either welded to the faceplates to develop their capacity (Type A), hot-rolled (Type B), or made of the same plate and bent and then welded with Complete-Joint-Penetration welds (Type C). The LTR states that the structural performance of each of these configurations is equivalent since each configuration consists of faceplates and fully developed diaphragm plates.

Based on its review of LTR Section 3.4 and LTR Section 7.0, the NRC staff finds that the structural behavior and performance of the three different fabrication configurations of DP-SC structural modules (Type A, B, and C), described and illustrated in LTR Figure 3-5 and Figure 3-6, would be equivalent or similar because (a) the welded connections indicated in LTR Figure 3-5(b) would fully develop the capacity of the connected elements, and (b) the configurations are similar or equivalent to those used in the load test specimens illustrated in LTR Figures 7-1 through 7-6 for the confirmatory NRIC Phase 1 prototype testing. The NRC staff further notes that, to ensure representative structural configuration and behavior to that evaluated in this SE, any DP-SC module configurations different from those described and illustrated in LTR Section 3.4 are outside the scope of the LTR. ***[L&C 8.1(f)]***

Based on its review of LTR Section 3.4, the NRC staff finds that it provides an adequate description and illustration of the DP-SC modular construction and configurations that will be used for DP-SC components of the BWRX-300 Integrated RB structures and components, including the SCCV and RPV pedestal.

4.0 TECHNICAL EVALUATION: BWRX-300 OVERALL ANALYSIS AND DESIGN APPROACH [INTEGRATED REACTOR BUILDING]

The NRC staff reviewed LTR Section 4.0 which describes and illustrates in Figure 4-1 the design code / proposed methodology jurisdictions and the proposed overall structural analysis and design approach, including loads and load combinations for the integrated RB DP-SC structures, including the SCCV.

GEH proposed the following design and construction approach for the BWRX-300 integrated RB, including SCCV, using DP-SC modules in the LTR.

- <u>DP-SC SCCV</u>: Since current design codes do not address the use of SC or DP-SC for the containment pressure boundary, GEH proposed design and construction rules in LTR Section 6.0 adapted from the ASME BPVC 2021 Edition, Section III, Division 2, Subsection CC, Articles CC-1000 through CC-6000 including Division 2 Appendices (LTR Reference 9-1 and hereafter referred to as ASME Code III-2), for materials, design, fabrication, construction, examination and testing of the SCCV to the extent they apply to a DP-SC containment without reinforcing steel or tendons (conforming as applicable with NRC RG 1.136, Revision 4), and further modified and supplemented it for DP-SC modular construction with supporting technical bases. Acceptance criteria for design of the SCCV, including mat foundation, is in accordance with ASME Code III-2 and discussed in LTR Section 6.6. Also, the LTR proposed adapting the ASME Code, Section XI, Subsections IWE and IWL (LTR Reference 9-5, hereafter referred to as ASME Code XI – IWE/IWL), as incorporated by reference with conditions in 10 CFR 50.55a(g)(4) for containment inservice inspection of the SCCV.

- <u>Non-containment DP-SC Integrated RB structures</u>: GEH proposed in LTR Section 5.0 modified criteria and requirements, with supporting technical bases, to American National Standard Institute (ANSI)/AISC N690-18, “Specification for Safety-Related Steel Structures for Nuclear Facilities" (LTR Reference 9-2, hereafter referred to as ANSI/AISC N690), Chapters NM, NN, and Appendix N9 (as endorsed in RG 1.243, Revision 1) for design, analysis, fabrication, construction, examination, and testing of BWRX-300 non-containment RB structural members built using DP-SC modules, including slabs, curved walls, and RPV pedestal. Acceptance criteria for design of the RB DP-SC structures, including mat foundation portion outside of the SCCV, and RPV pedestal are in accordance with ANSI/AISC N690, Appendix N9 "SC Walls," as endorsed in RG 1.243 and modified rules in LTR Section 5.0. Since design requirements of Appendix N9 to ANSI/AISC N690-18 are limited to straight conventional SC walls, modified and compensatory detailing and design requirements were developed in Section 5.0, which also addresses applicability of ANSI/AISC N690-18 to design of DP-SC floors and curved walls.

- Supporting Technical Bases: GEH provided in the LTR the supporting technical bases to justify the proposed approach of adapting, modifying, and supplementing the two NRC-endorsed existing codes and standards referenced above. These bases included cognizant current published technical literature (experimental and analytical) applicable to DP-SC, draft proposed next revision/edition of ANSI/AISC N690-XX standard issued for 2nd public comment in October 2023 (LTR Reference 9-59, hereafter referred to as Draft ANSI/AISC N690-XX), and the confirmatory NRIC Demonstration Program Phase 1 Prototype Testing (hereafter referred to as the NRIC Prototype Testing) summarized in LTR Section 7.0. The modified/supplemented rules allow use of the most current methods and technology while meeting regulatory safety goals. It should be noted that proposed changes in Draft ANSI/AISC N690-XX include horizontal SC structural elements (e.g., slabs, basemat) in addition to walls, and clarifies that both ties and steel headed stud anchors serve as shear connectors to enable composite action.

The LTR notes that the primary differences between the Class CC concrete containment addressed in ASME III-2 and the SCCV is that the DP-SC containment does not use reinforcement or tendons and does not use a separate liner that functions only as a leak barrier. In the case of DP-SC containments, the inner faceplate serves as the leak barrier, with the DP-SC composite section (i.e., both the inner and outer faceplates, diaphragm plate, and the concrete infill acting together) serves as the pressure-retaining/resisting boundary providing structural integrity for the containment.

LTR Section 4.3 states that the design loads and load combinations used for the design of the integrated RB structures are in accordance with: (a) Subarticle CC-3230 of 2021 ASME III-2, as supplemented by RG 1.136, for the SCCV; and (b) Section NB2.5 "Load and Resistance Factor Design (LRFD) provisions of ANSI/AISC N690-18, as supplemented by RG 1.243 for DP-SC RB structures and components.

The NRC staff finds the above approach proposed by GEH for design and construction of the BWRX-300 DP-SC Integrated RB structures and components including SCCV acceptable because: (a) the approach is based on adapting, modifying and supplementing the best applicable existing codes and standards endorsed by the NRC in RG 1.136 for ASME III-2 (code for concrete containments with steel liner) and RG 1.243 for ANSI/AISC N690-18 (specification for safety-related steel structures which includes SC walls); (b) the design loads and load combinations and structural acceptance criteria are consistent with the above codes, as supplemented by the corresponding NRC RGs; and (c) the approach is aligned with GDC 1 which is a focus of the NRC staff review in that, where generally recognized codes and standards are used, they shall be identified and evaluated for applicability, adequacy, and sufficiency and shall be supplemented or modified as necessary to assure a quality product in keeping with the required safety function.

LTR Section 4.1 describes that the One-Step Analysis Approach (as defined in Section 3.1.2 of ASCE 4-16) (LTR Reference 9-58) for structural analysis of the integrated RB under static and dynamic loads, including SSI, to adequately account for the effects of interaction of the deeply embedded structure with the surrounding subgrade is implemented in accordance with the guidance in Section 5.1 and 5.2 of NRC-approved LTR NEDO-33914-A “BWRX-300 Advanced Civil Construction and Design Approach” (ML22168A010). Further, LTR Section 4.2 describes that the 3D finite element (FE) model of the integrated RB is developed for the one-step analyses approach following the modeling guidelines in Section 5.1 of NRC-approved LTR NEDO-33914-A. The model uses thick shell elements with equivalent thickness, elastic modulus, Poisson’s ratio, and material density calibrated to match stiffness and mass properties of DP-SC modules, and damping values for DP-SC modules as discussed in LTR Sections 5.0 and 6.0.

The NRC staff finds the structural analyses and modeling approach acceptable because they follow the guidance in NRC-approved LTR NEDO-33914-A, and the use of thick shell elements for finite element analysis of SC modules is acceptable per provisions of ANSI/AISC N690-18, Appendix N9.

5.0 TECHNICAL EVALUATION: MODIFIED DESIGN RULES FOR NON-CONTAINMENT STEEL-PLATE COMPOSITE STRUCTURES [USING DP-SC MODULES]

LTR Section 5.0 describes the modified design rules, with supporting bases, for the BWRX-300 non-containment DP-SC structures adapted from the LRFD provisions of ANSI/AISC N690 standard and adjusted to address the following specific particulars of DP-SC modules proposed for BWRX-300 not currently addressed in the standard:

1) Modified ANSI/AISC N690, Appendix N9, design equations to compute DP-SC sectional capacities that account for contribution of diaphragm plates.

2) Effects of curvature on DP-SC walls.

3) Applicability of ANSI/AISC N690, Appendix N9, modified rules to DP-SC horizontal modules (e.g., floors).

The NRC staff notes that ANSI/AISC N690, Appendix N9, “Steel-Plate Composite Walls,” provisions are currently limited to conventional (or traditional) straight SC walls, and that LTR Section 5.0 discusses only provisions that differ from ANSI/AISC N690-18. It should also be noted that the parent (or baseline) specification for the ANSI/AISC N690-18 nuclear standard is ANSI/AISC 360-16, “Specification for Structural Steel Buildings and Commentary” (LTR Reference 9-62), and therefore ANSI/AISC N690-18 must be used in conjunction with ANSI/AISC 360-16 except where the LTR explicitly invokes ANSI/AISC 360-22.

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5.1 Design Parameters

LTR Section 5.1 and Figure 5-1 (proprietary) define and illustrate the geometric and material design parameters, nomenclature, and associated limits for DP-SC modules.

The NRC staff noted that the LTR included footnote (1) associated with the faceplate and diaphragm plate thickness (t_p) and yielding strength (F_y), which states:

> *"DP-SC faceplate and diaphragm plates can have different thicknesses and use different steel grades in the range allowed by the applicable design code/standard. Design equations presented in this report use the same t_p and F_y for DP-SC faceplate and diaphragm plates. These equations can be modified as required to reflect the design parameters for each DP-SC component."*

As indicated in the above cited footnote, the design equations presented in the LTR Sections 5.0 and 6.0 are based on the same thickness and material yield strength for the faceplates and diaphragm plates. As such the NRC staff review and approval of the LTR is based on equations as presented in the LTR and consistent with the confirmatory NRIC Prototype Testing. Therefore, the NRC staff imposes a limitation and condition that if the equations presented in the LTR are modified by an applicant for the use of different plate thickness or material yield strength (within bounds specified in the LTR Section 5.2.2) between the faceplates and diaphragm plates, the modified equations and supporting derivation shall be submitted for NRC staff review as part of a future application referencing the LTR. It is further clarified that if the equations are modified, the thickness and material yield strength of the inner and outer faceplates shall remain the same, which is consistent with existing code provisions and experimental data for SC/DP-SC construction. ***[L&C 8.2]***

LTR Section 5.1 states that minimum and maximum depths, t_{sc}, of DP-SC modules are in accordance with ANSI/AISC N690, Appendix N9, Section N9.1.1a provisions, which the NRC staff finds acceptable because it is consistent with the existing standard and limits the maximum section thickness to not exceed 60 inches based on existing experimental database. However, the LTR further states: *"In accordance with Section N9.1.1a of ANSI/AISC N690, any DP-SC section thickness greater than 60 in (1500 mm) is to be justified by experimental or numerical results to demonstrate the applicability and conservatism of Appendix N9 provisions to sections with greater section thicknesses."*

The NRC staff imposes a limitation and condition that SC or DP-SC section thickness or depth (t_{sc}) greater than 60 inches is not permitted consistent with AISC N690-18, Appendix N9, as endorsed in RG 1.243. This is because ANSI/AISC N690-18 Section N9.1.1a does not permit section thickness greater than 60 inches as claimed in the LTR, no representative experimental and numerical evidence was provided, nor was it tested in the NRIC Prototype Testing. Further, the cited statement in the LTR is a discussion in the Commentary to ANSI/AISC N690, Appendix N9, that does not appear to be representative of the proposed DP-SC and states that "experimental and numerical results" may be used, thus is incorrectly stated in the LTR. ***[L&C 8.3]***

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5.2 Materials

LTR Section 5.2 describes the concrete and steel-plate that will be used for the integrated RB DP-SC modules. The LTR states that concrete temperature limitations for operating and accident conditions will meet the requirements specified in Appendix E of ACI 349-13, and reduction in concrete mechanical properties at elevated temperature will be per Appendix N4 of AISC N690-18. The LTR also states that specified minimum yield strength (F_y) of steel plates will be in the range 50 ksi to 65 ksi, and that effect of elevated temperature on mechanical properties of steel materials is determined per Section NB3.3 of ANSI/AISC N690. The NRC staff finds these material considerations acceptable because they are based on appropriate standards that are endorsed by the NRC in RG 1.142 (for ACI 349-13) and RG 1.243 (for ANSI/AISC N690). The NRC staff notes that the 50 ksi to 65 ksi limits for specified yield strength (F_y) of materials used for steel plates applies to all integrated RB DP-SC modules, including the SCCV.

LTR Section 5.2.1, "Concrete Infill," states that self-consolidating concrete (SCC) is used as concrete infill for the integrated RB DP-SC modules. The NRC staff finds the use of SCC reasonable for DP-SC modules as it has been introduced in building codes (e.g., ACI 318-19) and being increasingly used in industry. Its use would be necessary for DP-SC configuration (which makes manual consolidation difficult) to achieve required workability (flow) and consistency/consolidation of the concrete through the diaphragm holes with minimal segregation. The SCC will be designed, qualified, and tested to industry standards (e.g., ACI 237R and related American Society for Testing and Materials (ASTM) standards) and follow best practices as indicated in LTR Section 6.2.1. The use of SCC is further supported by adequate performance demonstrated by its use in the confirmatory NRIC Protype test specimens.

The NRC staff noted that LTR Section 5.1 specifies the maximum reinforcement ratio (r) for the DP-SC walls as 0.10 (versus 0.05 in ANSI/AISC N690), which is based on proposed provisions in Second Public Review Draft ANSI/AISC N690-XX dated October 9, 2023 (LTR Reference 9-59, hereafter referred to as Draft ANSI/AISC N690-XX). This aforementioned draft is the proposed next edition of ANSI/AISC N690, and Section I1.6, "Requirements for Composite Plate Shear Walls," of its parent specification AISC 360-22 (LTR Reference 9-60). The staff further noted that this maximum reinforcement ratio in Draft ANSI/AISC N690-XX is also linked to an associated empirical equation of concrete compressive strength (f'c) as a function of reinforcement ratio (r) and steel yield strength (F_y). This equation is reproduced in LTR Section 5.2.1 as Equation [5-1], with a lower limit for f'c of 4 ksi and an upper limit of 10 ksi.

However, consistent with the specification in LTR Section 5.2.2 that yield strength (Fy) of the steel plates of DP-SC modules be in the range 50 ksi to 65 ksi, using maximum r = 0.10 and maximum Fy = 65 ksi, the upper bound of concrete compressive strength (f'c) based on the equation in LTR Section 5.2.1 would be limited to 8 ksi (55 MPa) and not 10 ksi (70 MPa). Therefore, the NRC staff imposes a corresponding limitation and condition that the maximum f'c shall be limited to 8 ksi. Further, this condition is also consistent with Section 4.2.3 in Appendix 4 of ANSI/AISC 360-22, referenced in LTR Section 5.5.1 for elevated temperature material properties, which states that the provision applies only to structural steels with specified minimum yield strength equal to 65 ksi or less, and to concrete with specified compressive strength equal to 8 ksi or less. ***[L&C 8.4]***

5.3 Composite Action

LTR Section 5.3 addresses the requirements for composite action of the DP-SC section. Composite action is achieved through shear connectors that enable integrated action between the infill concrete and the steel faceplates as a single unit with improved combined strength and stiffness. LTR Section 5.3 considers as shear connectors steel headed stud anchors as well as ties where ties are discrete structural steel components that connect the two faceplates of the DP-SC module at regular intervals. The shear connectors, namely their shear capacity and spacing, are then designed to (1) achieve development of the steel faceplates yield strength over the specified development length and (2) prevent interfacial shear failure before out-of-plane shear failure of the composite section.

ANSI/AISC N690-18 only considers the contribution of steel headed anchors to enabling composite action by meeting the two requirements above for achieving composite action. This is the approach used with traditional composite sections, which used steel shapes connected to one side of concrete slabs or elements. SC sections including the DP-SC modules use steel faceplates on both sides of a concrete slab. In addition to the steel headed studs, the steel faceplates are also connected to each other through ties embedded in the concrete. It has been recognized in the public drafts of ANSI/AISC N690-XX, dated October 9, 2023, and May 2, 2024, that these ties can also contribute to the enabling of composite action. LTR Section 5.3 also invokes that the presence of steel ties in the steel-plate composite section can also contribute to the enabling of composite action in addition to the steel headed studs. Accordingly, LTR Section 5.3 provides a mechanistic approach to calculate the requirements for the shear capacity of the two types of shear connectors and their respective spacing to achieve composite action. That mechanistic approach follows the provisions in Section N9.1.4 of the public review draft of ANSI/AISC N690-XX, dated October 9, 2024. The staff reviewed the methodology in Section 5.3 and 5.3.1 against the most recent public review draft, dated May 2, 2024. There are not significant changes between the ANSI/AISC N690-XX public review drafts of May 2024 and October 2023 pertaining to the requirements for achieving composite action.

The requirements in Section N9.1.4 in ANSI/AISC N690-XX are for shear connectors in the form of ties that are discrete (discretely spaced) structural components such as steel shapes, frame, or bars connecting the faceplates at regular intervals. **[[**

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LTR Section 5.3 also states that the BWRX-300 construction uses yielding steel headed stud anchors in all composite construction and meets the requirements for steel headed anchors per ANSI/AISC N690-18, Appendix N9, Section N9.1.4a.

Test data reported in Chapter 7 of the LTR confirms that composite action can be achieved for the reported tests. The design methodology in LTR Section 5.3 for the interfacial shear requirements for achieving composite action is also consistent with the equations used in LTR Section 5.7.5 for the out-of-plane section shear strength which has been verified against test data reported in Chapter 7 of the LTR for out-of-plane shear strength. The testing program referred to in Chapter 7 of the LTR used composite sections with both steel headed steel anchors as well as the diaphragm plate ties. This is also consistent with the LTR methodology because the LTR Section 5.3 states that only in localized areas where the composite action requirements of Section N9.1.4b of public draft of ANSI/AISC N690-XX and the faceplate slenderness requirements of Section N9.1.3 of public draft of ANSI/AISC N690-XX can be achieved by the idealized diaphragm plate ties alone, steel headed stud anchors may not be used to facilitate the construction of DP-SC modules.

Based on the above review, the NRC staff finds that the requirements in LTR Section 5.3 complemented with the equations in LTR Section 5.3.1 are acceptable to ensure composite action for the DP-SC modules because it follows the approach in public draft of ANSI/AISC N690-XX that recognizes that both steel headed stud anchors as well as discrete ties contribute to achieving the composite action. This approach is also confirmed with test results which show that composite action was achieved in the experiments for SC sections with diaphragm plates with holes. The test specimens used both steel headed stud anchors as well as discrete ties, which are the parts of the diaphragm plates between their holes. The DP-SC modules for the BWRX-300 also use both types of shear connectors except in localized areas where steel headed stud anchors are not used to facilitate construction.

5.3.1 Shear Connectors Capacity

LTR Section 5.3.1 provides the actual equations used in the LTR methodology to verify that the DP-SC modules achieve composite action. The equations provided in LTR Section 5.3.1 are consistent with the approach described in LTR Section 5.3 and with the requirements in Section N9.1.4b of the public review draft of ANSI/AISC N690-XX. **[[**

]] The staff reviewed the equations in Section N9.1.4b of the public draft of ANSI/AISC N690-XX and concluded that they follow the mechanistic considerations invoked for the achievement of composite action using both steel headed stud anchors as well as discrete ties. The adjustments to those equations in LTR 5.3.1 are only used to capture the differences needed for achieving the yield strength of the faceplates in the directions parallel and perpendicular to the diaphragm plates.

The NRC staff finds the specific equations in LTR Section 5.3.1 to satisfy the requirements for composite action, namely (1) the requirement to develop the yield strength of the faceplates and (2) the requirement to prevent interfacial shear failure before out-of-plane shear failure of the composite section, to be acceptable in meeting the approach in LTR Section 5.3 because they appropriately follow the equations in Section N9.1.4b of the public review daft of ANSI/AISC N690-XX with appropriate adjustments to account for the orientation of the diaphragm plates.

The NRC staff notes that the LTR adopts in part the proposed provisions in Draft AISC N690-XX dated October 9, 2023, "Specification for Safety-Related Steel Structures for Nuclear Facilities" (2nd public review draft), for design of shear connectors (LTR Section 5.3, 5.4) for composite action and maximum reinforcement ratio and corresponding concrete compressive strength (LTR Section 5.1 and 5.2.1), which the staff has accepted on a limited basis as justified and based on its participation in codes and standards committees. The NRC staff conducted its review against the most recent public review draft dated May 2, 2024, of the next edition of ANSI/AISC N690-XX noting that there were no significant changes from the October 2023 public review draft. However, the use of public review draft in the LTR shall not in any way be construed as NRC endorsement of Draft AISC N690-XX until after formal staff endorsement of the published next edition. ***[L&C 8.5]***

5.4 <u>Diaphragm Requirements</u>

The NRC staff noted from LTR Section 5.4 that spacing of diaphragm plates is limited to not exceed panel thickness, t_{sc}, which is consistent with maximum allowed tie spacing in ANSI/AISC N69-18 and ACI 349-13, and acceptable since diaphragm plates serve as ties in DP-SC and both standards are endorsed by NRC in RGs 1.243 and 1.142. The LTR also states that the diaphragm plates shall meet the next edition public Draft ANSI/AISC N690-XX, Appendix N9, Section N9.1.5 [noting the LTR has a typo "N9.5.1"] which provides an additional requirement to also limit tie spacing based on tie spacing-to-faceplate thickness ratio in longitudinal and transverse directions [Equations 9A-N-6 and 9A-N-6M in the draft standard]. The NRC staff finds this acceptable because it imposes an additional stringent requirement for tie spacing.

5.5 <u>Determination of Effective Stiffness of Steel-Plate Composite Elements</u>

LTR Section 5.5 describes determination of effective stiffness, geometric and material properties of DP-SC elements for structural FE analysis, and analyses involving accident thermal loads to determine the structural demands (required strength).

The NRC staff noted that **[[**

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The NRC staff finds that the equations and calibration procedure used to establish the equivalent thickness and material properties and effective stiffness values of DP-SC panels for use in the elastic FE analysis using shell elements are acceptable because they are consistent or developed based on established engineering principles in recognized standards ANSI/AISC N690-18 (endorsed in NRC RG 1.243) and ANSI/AISC 360-22 (axial stiffness).

5.5.1 Heat Transfer Analysis

From LTR Section 5.5.1, the NRC staff noted the analyses for load combinations involving thermal loads also include heat transfer analyses. The NRC staff noted that the BWRX-300 heat transfer analysis will be conducted using the explicit model approach to estimate temperature time histories and through thickness temperature profiles accounting for time lag effects between the different materials. These temperature histories and through-section temperature profiles are considered in the structural FE analyses for accident thermal load conditions.

LTR Section 5.5.1 states the approach is similar to that for structural design for fire conditions in Section 4.2.4c, "Design by Advanced Method of Analysis," of ANSI/AISC 360-22, Appendix 4. An explicit model, representing the different components of steel plates, discretized studs, concrete infill, and contact between different components, and simulating both thermal and mechanical responses will be used. This model based on temperature-dependent properties (per Section 4.2.3 of ANSI/AISC 360-22, Appendix 4, as modified per N690-18 Appendix N4) of the steel plates and concrete infill will be used to estimate the temperature time histories and through-section temperature profiles produced by the thermal accident conditions for the different thermal gradient scenarios, and to calculate maximum corresponding structural demands (e.g. axial and/or flexure), both globally and locally.

The NRC staff finds that the proposed heat transfer analysis using explicit modeling and temperature-dependent material properties provides realistic DP-SC through-section temperature time history profiles and is required for accounting for time lag effects between the different (concrete, steel) materials, for use in the DP-SC Integrated Reactor Building FE analysis for accident thermal conditions and is therefore acceptable.

5.5.2 Damping Values

The NRC staff noted from the LTR Sections 5.5.2 and 6.4 that damping values used in structural analysis of DP-SC RB structures and SCCV that account for dissipation of energy will be in accordance with Tables 1 and 2 of NRC RG 1.61, Revision 2 (LTR Reference 9-29), which include damping values for SC structures for both SSE and OBE, are therefore, acceptable.

5.6 Effective Stiffness of Semi-Rigid Connections

The NRC staff noted from LTR Section 5.6 that for DP-SC semi-rigid connections, equivalent connection (joint) rotational stiffness, for use in the structural analysis model, will be computed using a component-based model approach in Article 6.3 of EN 1993-1-8, "Eurocode 3, Design of Steel Structures - Part 1-8: Design of Joints" (LTR Reference 9-63). The component-based model uses the behavior (flexibilities) of individual basic components within a joint (e.g., bolt, welds, endplate, flange) to build a realistic representation of a connection load-deformation characteristics used to calculate the rotational joint stiffness.

The NRC staff finds this approach reasonable and acceptable because it is based on a recognized European standard, and since the approach considers behavior of individual joint components, it can be applied to determine rotational stiffness of DP-SC semi-rigid connections. However, the NRC staff will review detailed implementation of this approach when an application is submitted for the BWRX-300 SMR.

5.7 Section Capacities of Steel-Plate Composite Elements

The NRC staff notes from LTR Section 5.7 that the capacities (or available strength) of DP-SC members **[[**

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5.7.1 Uniaxial Tensile Strength

The NRC staff noted that uniaxial tensile strength of DP-SC modules is **[[**

]] and is therefore, acceptable.

5.7.2 Compressive Strength

The NRC staff noted from LTR Section 5.7.2 that **[[**

]] The NRC staff finds the above approach to calculate compressive strength of DP-SC section acceptable because it **[[**

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]] and is consistent with ANSI/AISC N690-18, as endorsed by RG 1.243, subject a limitation and condition as noted below.

The NRC staff notes from Commentary **[[**

]] ***[L&C 8.6]***

5.7.3 Out-of-Plane Flexural Strength

5.7.3.1 Perpendicular to Diaphragm Span

The NRC staff noted from LTR Section 5.7.3.1 that in the direction perpendicular to the diaphragm plate span (LTR Figure 5-5 - proprietary), the out-of-plane flexural strength is determined based on the limit state of yielding of the faceplates using LTR Equation [5-22] the same as Equation A-N9-19 in Section N9.3.3 of ANSI/AISC N690-18. The NRC staff finds this acceptable because it neglects any contribution from the diaphragm plates and therefore the same equation in ANSI/AISC N690-18 for traditional SC walls can be used, and further the results of the NRIC OOPV-1 test specimen in LTR Section 7.0 confirmed that the equation is conservative in estimating out-of-plane flexural capacity.

5.7.3.2 Parallel to Diaphragm Span

The NRC staff noted from LTR Section 5.7.3.2 that in the direction parallel to the diaphragm plate span (LTR Figure 5-4 - proprietary), the out-of-plane flexural strength is **[[**

]] The NRC staff finds this approach acceptable because (a) it is based on proven sectional analysis principles for reinforced concrete using analogous DP-SC sectional stress/force distribution shown in LTR Figure 5-7 (proprietary) and demonstrated in literature, and (b) the results of the NRIC OOPV-2 test specimen in LTR Section 7.0 confirmed that the equation is conservative in estimating out-of-plane flexural capacity.

5.7.4 In-Plane Shear Strength

The NRC staff noted from LTR Section 5.7.4 that in-plane shear strength is calculated per Section N9.3.4 of Appendix N9 of ANSI/AISC N690-18 for traditional SC walls. The NRC staff finds this acceptable for DP-SC modules because in-plane shear strength is determined or governed by the yielding behavior of the faceplates only, without any contribution from the diaphragm plates.

5.7.5 Out-of-Plane Shear Strength

The NRC staff noted from LTR Section 5.7.5 that **[[**

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5.7.5.1 Perpendicular to Diaphragm Span

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The NRC staff noted from LTR Section 5.7.5.1 that the nominal out-of-plane (OOP) shear capacity of DP-SC modules, in the direction perpendicular to diaphragm plate span (LTR Figure 5-5 – proprietary), is calculated **[[**

]] which are consistent with the methodology in Section N9.3.5 of ANSI/AISC N690-18 endorsed by NRC RG 1.243. The design strength is obtained by applying the resistance factor for shear to the nominal strength.

The NRC staff finds the above approach to calculating OOP shear capacity acceptable because it is consistent with the methodology in Section N9.3.5 of ANSI/AISC N690-18 endorsed by NRC RG 1.243, **[[**

]]

5.7.5.2 Parallel to Diaphragm Span

The NRC staff noted from LTR Section 5.7.5.2 that the nominal OOP shear capacity of DP-SC modules, in the direction of diaphragm plate span (LTR Figure 5-4 – proprietary), is calculated **[[**

]] The NRC staff finds this approach acceptable because **[[**

]] using established analogous principles in reinforced concrete, which is then added to the concrete contribution calculated using previously discussed LTR Equation 5-26

5.7.5.3 Two-Way (Punching) Shear

The NRC staff noted that punching shear strength of DP-SC modules is calculated as the minimum of the out-of-plane shear strength in the two directions (if different) multiplied by perimeter of the punching shear length at the critical section at half the section thickness. The NRC staff finds this acceptable because it is consistent with the approach for traditional SC sections as well as reinforced concrete.

5.7.6 Out-of-Plane Shear Force Interaction

The NRC staff noted from LTR Section 5.7.6 that the interaction of out-of-plane shear forces in DP-SC modules is calculated using the Equation A-N9-24b for yielding shear reinforcement in Appendix N (Section N9.3.6a of public review Draft of ANSI/AISC N690-XX), noting that for the

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perpendicular to diaphragm span direction case, where the spacing of shear reinforcement is greater than 0.5t_{sc} and V_c is governed by steel contribution only, $V_{c\ conc}$, in the equation is set to zero. The NRC staff finds this approach for interaction of out-of-plane shear forces acceptable because the equation in Draft ANSI/AISC N690-XX is adapted consistent with the mechanistic behavior described in LTR Section 5.3.1 to assure yielding shear connectors, and the exponent of 2 in the interaction equation is established using Von Mises criterion for the yielding reinforcement.

5.7.7 In-Plane Membrane Forces and Out-of-Plane Moments Interaction

The NRC staff noted from LTR Section 5.7.7, the design adequacy of DP-SC panel sections for combined in-plane membrane forces and out-of-plane moments is checked using **[[ ]]** which is endorsed in RG 1.243 for traditional SC walls. Therefore, the NRC staff finds this acceptable for DP-SC modules because in addition to being endorsed in NRC guidance for SC walls, **[[ ]]**

5.8 <u>Design for Impactive and Impulsive Loads</u>

LTR Section 5.8 provides the LTR methodology for the design of the DP-SC panels to resist the effects of impulsive and impactive loads.

LTR Section 5.8 states that the design for impactive loads satisfies criteria for both local effects and overall structural response in agreement with NUREG-0800, SRP Section 3.5.3 which is acceptable.

5.8.1 Design Allowable

5.8.1.1 General

LTR Section 5.8.1.1 states that the DP-SC panels are designed to resist loads in the normal and severe environmental load combination to stay essentially elastic. This is acceptable because it agrees with ANSI/AISC N690-18 as endorsed in RG 1.243.

LTR Section 5.8.1.1 states that DP-SC modules designed to resist impulse loads and dynamic effects in the abnormal and extreme environmental load categories are allowed to have permanent, plastic deformations. This is acceptable because it agrees with ANSI/AISC N690-18 as endorsed in RG 1.243.

LTR Section 5.8.1.1 states that the design of DP-SC modules to resist impulsive loads and dynamic effects in the abnormal and extreme environmental load categories is controlled by limiting the support rotation and ductility as well as steel and concrete strains. This is acceptable because it agrees with the approach in ANSI/AISC N690-18 as endorsed by RG 1.243.

5.8.1.2 Allowable Stresses

LTR Section 5.8.1.2 provides dynamic increase factors not to be exceeded that multiply static material strengths of steel and concrete to determine section strength. Those factors are acceptable because they are the same factors in ANSI/AISC N690-18 as endorsed by RG 1.243.

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The NRC staff also finds that in Section 5.8.1.2, the dynamic increase factors in LTR Table 5-1 are applicable specifically for steels with specified yield strength up to 65 ksi, which is within the 50 ksi – 65 ksi range of steel specified yield strength stipulated in the LTR and are the same as specified in NEI 07-13, which is endorsed in NRC RG 1.217 and therefore, acceptable.

5.8.1.3 Allowable Limits

LTR Section 5.8.1.3 provides the controlling support rotation, ductility ratios, and concrete and steel strains for the design of DP-SC modules designed to resist impulsive loads and dynamic effects in the abnormal and extreme environmental load categories.

<u>Controlling Support Rotations and Ductility Ratios</u>

The staff finds acceptable for use with global DP-SC component response (as opposed to local effects) the allowable support rotations and ductility factors in Table 5-2, for superficial damage, limited damage, and moderate damage, in conjunction with the footnotes for Table 5-2 and the bullets at the start of Section 5.8.1.3. The allowable limits follow those in ANSI/AISC N690-18, Section N9.1.6b, with the exceptions and additions in Regulatory Positions 11.1.1 to 11.1.8 and 11.2. LTR Table 5-2 differs, in an acceptable manner, from the positions in RG 1.243 in the following cases:

- LTR Table 5-2 uses an allowable support rotation of 1-degree instead of a ductility ratio of 3 in Regulatory Position 11.1.6. Footnote 6 to Table 5-2 justifies that the 1-degree rotation may be used because it reflects a level of damage that corresponds to a structural drift that governs the entire integrity of the structure in the manner that the ductility factor of 3 intends to capture.

- LTR Table 5-2 uses an allowable support rotation for in-plane flexure of shear walls of 1.5 degrees, which is the same used in Table 14 of the International Atomic Energy Agency (IAEA) Safety Reports (SR) series No. 87 (LTR Reference 9-67) for moderate damage of in-plane flexure of shear walls.

- LTR Table 5-2 uses an allowable ductility ratio of 1.5 for in-plane shear of DP-SC diaphragms which is the same used in Table 14 of the International Atomic Energy Agency (IAEA) SR series No. 87 for in-plane shear.

The allowable ductility ratios and rotations in Table 14 of the International Atomic Energy Agency (IAEA) Safety Reports (SR) series No. 87 (LTR Reference 9-67) are for reinforced concrete structural components. Allowable ductility and rotations for reinforced concrete components have been shown to be applicable to steel plate composite structural components, and generally conservatively applicable, as recognized in Appendix N9 of ANSI/AISC N690-18 as endorsed by RG 1.243.

LTR Table 5-2 uses an allowable ductility ratio of 3.0 for in-plane shear of DP-SC diaphragms for which footnote 9 to LTR Table 5-2 says is used in IAEA SR series No. 87. However, the allowable ductility ratio for in-plane shear of shear walls is 1.5 in Table 14 of the IAEA SR series No. 87. Therefore, the NRC staff imposes a limitation and condition that since LTR Section 5.8.1.3 does provide a justification for the allowable ductility ratio of 3.0 for in-plane shear of shear walls in Table 5-2, the ductility ratio for in-plane shear shall be limited to 1.5 consistent with Table 14 of IAEA SR No.87. ***[L&C 8.7(a)]***

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Further, the second bullet of LTR Section 5.8.1.3 says that “for DP-SC containment under DBAs … (i.e., equivalent load combinations per U.S. NRC RG 1.136) the acceptable damage criteria are per ASME BPVC, Section III, Division II, Subsection CC, Paragraph CC-3923, but not less than the superficial damage criteria per IAEA SR No. 87 listed in Table 5-2 and Table 5-3.” To avoid potential ambiguity in this statement, the NRC staff further clarifies through a limitation and condition for DP-SC containment under DBAs that: For normal and severe environmental load categories, the allowable limits for ductility, support rotation, and strain shall not exceed those for superficial damage in LTR Tables 5-2 and 5-3; and for abnormal, extreme environmental, and abnormal and extreme environmental load categories, the allowable limits for ductility, support rotation, and strain shall not exceed those for limited damage in LTR Tables 5-2 and 5-3. ***[L&C 8.7(b)]***

Additionally, in LTR Table 5-2, the evaluations and criteria for design extension events Tier 2 (DEE-2) as defined in IAEA SR 87 and corresponding severe damage criteria in LTR Table 5-2 are beyond the scope of NRC regulations and regulatory guidance cited in LTR Section 2, and therefore outside the scope of this LTR. ***[L&C 8.1(h)]***

<u>Controlling Steel and Concrete Strains</u>

LTR Table 5-3 provides allowable strains for steel for superficial damage, limited damage, and moderate damage which would be used for impact or impulse design for global DP-SC component response, as opposed to local effects.

The steel strains for moderate damage in LTR Table 5-3 are consistent with the limiting steel strains for carbon steel plates and stainless-steel plates in Table 2-2 of NEI 07-13. The allowable strain for moderate damage for carbon steel in LTR Table 5-3, 0.05, is also the same as the allowable strain in Regulatory Position 11.1.4 in RG 1.243.

The allowable strains in LTR Table 5-3 for superficial damage are the same in Table 13 of the IAEA SR series No. 87. These strains are the same as those for steel plates in footnote (4) to LTR Table 5-2. The strains for limited damage in LTR Table 5-3 are simply taken to be half of the strains for moderate damage which is acceptable for the use of limited damage in the LTR.

The LTR only defines the allowable strain for concrete in compression that correspond to essentially elastic behavior (superficial damage). Specifically, footnote (4) to the LTR Table 5-2 defines the allowable concrete strain in compression for essentially elastic behavior (superficial damage) as 0.35 percent, which is the same value used in Table 13 of the IAEA SR series No. 87.

For the above reasons, the staff finds the allowable strains for steel in LTR Table 5-3 and the allowable strain for concrete in footnote (4) to LTR Table 5-2 acceptable.

5.8.2 Missile Impact Design for Local Failure

LTR Section 5.8.2 provides the methodology for the design of DP-SC structures to prevent local failure from missile impact. The methodology in LTR Section 5.8.2 includes analysis to prevent perforation of the DP-SC structure.

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The methodology in LTR Section 5.8.2 requires that the faceplate thickness required to prevent perforation under impact loads is at least 25 percent greater than that calculated using rational methods addressed in LTR Section 5.8.2.2. This statement follows Section N9.1.6c of ANSI/AISC N690-18 endorsed by RG 1.243.

Section 5.8.2 includes two methods to design the DP-SC modules for the effects of impactive loads. One method, described in LTR Section 5.8.2.1 uses explicit dynamic finite element analyses. The other method, described in LTR Section 5.8.2.2, is an alternative to the method in in Section 5.8.2.1 and uses empirical methods based on mechanical-physical models and test data.

5.8.2.1 Explicit Dynamic Inelastic Analysis

The method in LTR Section 5.8.2.1 uses two explicit finite element analysis methodologies that follow NEI 07-13 methods of analysis to analyze missile impacts for local effects. The approach in NEI 07-13, which has been endorsed by the staff in RG 1.217, was developed for reinforced concrete walls including reinforced concrete walls with liners and steel plate shells. LTR Section 5.2.8.1 augments the methodology in NEI 07-13 to address steel plate composite structures, including steel plate composite structures with DP-SC modules.

The staff considers the method in LTR Section 5.8.2.1 for the use of explicit finite element analyses to design DP-SC modules for local effects of missile impact acceptable because it follows the explicit finite element methods in NEI 17-03 augmented with approaches to consider steel plate composite modules including DP-SC modules.

5.8.2.2 Alternative Rational Methods

LTR Section 5.8.2.2 states that an alternative methodology to design DP-SC modules to prevent local perforation that uses empirical methods based on mechanical-physical considerations and test data may also be used and that scabbing of DP-SC panels is not a concern because the rear faceplates of DP-SC structures would prevent scabbing. This statement is acceptable to the staff in that the alternative rational method for design to prevent perforation considers failure of the rear faceplate as perforation of the DP-SC modules. With this approach, prevention of perforation also prevents scabbing.

LTR Section 5.8.2.2 also states that the diameter of local areas for missile impact will comply with the maximum diameter for diameter of local impact areas in Paragraph CC-3931 of the ASME Code III 2, which is acceptable to the staff.

LTR Section 5.8.2.2 says that Subsection 5.8.2.2.1 illustrates the conservatism of the methodology used for calculating the perforation resistance curve for NRIC missile impact tests referred to in Chapter 7.0 of the LTR. Subsection 5.8.2.2.1 does not by itself illustrate that conservatism. Instead, Section 5.8.2.2.1 and Section 7.3.5 illustrate that conservatism. Section 5.8.2.2.1 provides the equations for the alternative rational method which are those in the method in Reference 9-69 that LTR Section 7.3.5 says is conservative when applied to the NRIC missile impact test data referred to in LTR Chapter 7.0, Section 7.2.6.

5.8.2.2.1 Steel Plate Thickness Preventing Perforation

LTR Subsection 5.8.2.2.1 provides the equations for the Alternative Rational Method, that is based on LTR Reference 9-69, to design DP-SC modules for local effects, whose criteria is perforation prevention.

The general approach of the equations for the alternative method to prevent perforation for missile impacts follow a mechanistic model for the missile perforation of a SC module that is an extension of the method already recommended in the Commentary Section C-A-N9.1.6c of ANSI/AISC N690-18. This is a method that follows a combination of a mechanistic process to achieve perforation in combination with established equations for penetration of a missile for concrete. The method thus developed is then verified against the NRIC test data for missile impact in DP-SC modules referred to in LTR Section 7.0. The equations for the alternative rational method in LTR Section 5.8.2.2.1 are also the same used in Section N10.3.2 for local response evaluation of missile impacts into SC modules in the public draft of ANSI/AISC N690-XX, dated May 2, 2024, which is the third public review draft of ANSI/AISC N690-XX.

The staff finds the equations in LTR Subsection 5.8.2.2.1 for the alternative rational method to design DP-SC modules for missile perforation acceptable when used in conjunction with the statement in LTR Section 5.8.2 that the faceplate thickness required to prevent perforation under impactive loads is at least 25 percent greater than that calculated using rational methods discussed in Section 5.8.2.2. This is because the empirical equations in Subsection 5.8.2.2.1 follow an underlying mechanistic model of the perforation of a SC module by a hard missile and have been shown to be conservative when applied to the NRIC missile impact tests on DP-SC modules referred to in LTR Section 7.0. These equations also follow the recommendation in a User Note in Section N9.1.6c of ANSI/AISC N690-XX, which recommends using a set of equations that use a mechanistic penetration model for the derivation of the perforation process that is a precursor to the model used in LTR Subsection 5.8.2.2.1. In addition, the equations in LTR Subsection 5.8.2.2.1 are the same as those in the Section N10.3.2, for the design of SC modules to prevent missile perforation, of the second and most recent public draft of ANSI/AISC N690-XX, dated May 2, 2024.

5.8.3 Impact or Impulse Design for Global Response

LTR Section 5.8.3 provides the methodology to determine the global response of DP-SC structures subject to impulsive or impactive loads. The staff understands that the global response of DP-SC structures refers to the response of whole structural components, except for compartment pressurization, as opposed to the local response to impactive loads. The methodology in items 1), 2), and 3) of LTR Section 5.8.3 are acceptable to the staff because they follow Section N9.1.6c of ANSI/AISC N690-18 for the response determination of impulsive loads.

LTR Section 5.8.3 includes an additional methodology element to address the need to verify the dynamic response of the DP-SC component to shear at the supports, and punching shear adjacent to the load with the added requirement that for impact loads perforation should be used in lieu of punching shear requirements. Both of those requirements are acceptable because those limit states need to be verified. Methodology Element 4 also complies with RG 1.243 Regulatory Position 11.1.8.3 for the effective width of the critical section for shear beam capacity at the supports.

LTR Section 5.8.3 explicitly states that the results of the global analyses comply with the ductility limits in Table 5-2 of LTR Section 5.8.1.3. LTR Section 5.8.3 does not explicitly refer to compliance with rotational limits in LTR Section 5.8.1.3 and does not explicitly refer to compliance with the strain limits in Table 5-2 and Table 5-3 of LTR Section 5.8.1.3, respectively. According to Footnote (2) to LTR Table 5-2, when flexure controls, the criteria in terms of support rotations from Table 5-2 and in terms of strains from Table 5-3 are to be fulfilled simultaneously to control damage. Regulatory position 11.1.4 in RG 1.243 says that in addition to the support rotations and strain criteria, the ductility limit in LTR Table 5-2 should also be met. When flexure controls, the general approaches described in Section 5.8.3 should also be applicable to evaluate compliance with rotational limits in LTR Section 5.8.1.3 as well as the strain limits in Table 5-3 of LTR Section 5.8.1.3. To evaluate the strain limits, a time-history analysis, Item 3 in Section 5.8.3, used in conjunction with finite element models and adequate material properties should be used for direct determination of the material strains.

Therefore, the NRC staff imposes a Limitation and Condition that for flexure-controlled DP-SC components, in accordance with Footnote (2) to LTR Table 5-2 and regulatory position C 11.1.4 in RG 1.243, the criteria in terms of support rotations from LTR Table 5-2, in terms of ductility from LTR Table 5-2, and in terms of strains from LTR Table 5-3 shall all be met to control damage. ***[L&C 8.7(c)]***

5.8.4 Aircraft Impact Evaluation

LTR Section 5.8.4 states that malevolent aircraft impact evaluations will be performed using methodologies in NEI 07-13 endorsed in RG 1.217 (see LTR Section 2.3.11) to meet acceptance criteria of 10 CFR 50.150 considering both local and global structural failure modes of DP-SC modules. The LTR states that the global stability analysis to investigate the structural integrity of the RB during and after impact will be performed using explicit dynamic analyses following the guidance in NEI 07-13; however, specific requirements and approaches for aircraft impact explicit dynamic analyses are outside the scope of the LTR.

The NRC staff finds GEH's approach to perform aircraft impact assessment required by 10 CFR 50.150 reasonable because it will follow NRC-endorsed methodologies in NEI 07-13 and guidance in NRC RG 1.217 and NUREG-0800 SRP, as applicable to DP-SC. The NRC staff further notes that specific requirements and approaches for aircraft impact explicit dynamic analyses are outside the scope of the LTR. ***[L&C 8.1(g)]***

5.9 <u>Design of Steel-Plate Composite Floors</u>

From review of LTR Section 5.9, the NRC staff noted that **[[**

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5.10 Design and Detailing Requirements Around Openings

LTR Section 5.10 states design and detailing of the RB floor and wall penetrations and openings will meet the requirements in Section N9.1.7 of ANSI/AISC N690-18, as applicable to DP-SC modular construction. The NRC staff finds this reasonable because design and detailing of openings will meet requirements of a recognized NRC-endorsed standard in NRC RG 1.243.

5.11 Design of Steel-Plate Composite Connections

The NRC staff noted from LTR Section 5.11 that **[[**

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The NRC staff finds the above general approach for splice and connection design of DP-SC modules reasonable because they are based on principles of structural mechanics and recognized industry standards endorsed for SC walls in NRC RG 1.243 and related detailed guidance and follow and are supplemented by cognizant literature. However, since connections could be the weak link, the NRC staff will perform a detailed review of connection design for the integrated RB DP-SC modules when an application for the BWRX-300 SMR is submitted. Additionally, since the LTR does not provide sufficient detail of the specific connection design which may be developed only during detailed design, the NRC staff also imposes the following limitation and conditions related to connection design and detailing.

LTR Section 5.11 states **[[**

]] If the higher concrete contribution stated above is used, the recommended supporting technical basis with peer review shall be submitted for NRC staff review as part of a future application referencing the LTR. ***[L&C 8.8]***

Also, transfer of forces and moments (e.g., horizontal reaction) from the inclined RB roof to the RB cylindrical wall and related connections, which does not appear to be addressed in the LTR, shall be addressed in detailed design and made available for NRC staff review as part of a future application referencing the LTR. ***[L&C 8.9]***

Additionally, design implementation of connections between DP-SC slabs (including basemat) and DP-SC walls, DP-SC wall-to-wall, and splices and ventholes of DP-SC modules shall be addressed in detailed design and made available for NRC staff review as part of a future application referencing the LTR. ***[L&C 8.10]***

5.12 Effect of Curvature on Behavior of Steel-Plate Composite Structures

The NRC staff reviewed the commentary to Appendix N9 of ANSI/AISC N690-18 and noted that if the SC elements have any curvature, the effects of curvature on detailing and design need to be evaluated.

From review of LTR Section 5.12, the NRC staff noted that in curved wall applications, the most unique components of force demands are the out-of-plane moment and shear force caused by the curvature of a wall subjected to axial forces which are not induced in straight walls. The NRC staff further noted that experimental and analytical studies by Wang et al (2021; LTR Reference 9-74) compared the results of flat walls and curved walls under constant compressive load and cyclic in-plane and out-of-plane loading; the results of the studies found that curvature effects on the in-plane and out-of-plane flexural behavior of SC walls were found to be negligible for radius of curvature-to-wall panel thickness ratios greater than 2.0. Based on the study, the LTR states that the integrated RB curved walls are designed and detailed to have a radius-to-wall panel thickness greater than 2.0.

The NRC staff further notes that since curvatures of the integrated RB walls are included in the FE model, the effects of curvature on structural demands under design loads is captured in the structural analysis. In regard to fabrication and detailing for curved modules, from LTR Section 3.4 (refer SE Section 3.2), faceplates are rolled first into the required curvature, and then the diaphragm plates are welded to the curved faceplates to create a curved multi-web DP-SC subassembly. However, the NRC staff finds that any residual stress or strain resulting from rolling of the curved plates needs to be evaluated and incorporated in detailed design.

Based on the above review, the NRC staff finds that the proposed LTR approach has adequately evaluated the effects of curvature on the detailing and design of curved DP-SC modules provided the integrated RB curved DP-SC walls (including SCCV walls) are (a) designed and detailed to have a radius of curvature-to-wall panel thickness greater than 2.0 without exception, and (b) any residual stresses and strains resulting from rolling of the curved plates is evaluated and incorporated in detailed design. Therefore, the NRC staff imposes a limitation and condition to the above effect. ***[L&C 8.11]***

5.13 Fire Rating and Capacity Under Fire Condition Evaluation

The NRC staff noted from LTR Section 5.13 that the design and evaluation criterion for structural steel components of DP-SC modules for unintended fire conditions is based on provisions of Appendix 4 “Structural Design for Fire Conditions” of ANSI/AISC 360-22 (LTR Reference 9-60), as modified by Appendix N4 of ANSI/AISC N690-18, and qualified for the rating period in conformance with ASTM E119 (LTR Reference 9-75) and ANSI/AISC N690-18. The NRC staff also noted that all BWRX-300 DP-SC modules are designed to have a fire resistance rating of not-less-than 3 hours. The LTR provides fire rating criteria for the BWRX-300 critical DP-SC components, which include (a) the exposure time required to increase the temperature levels on the unexposed side of the fire barrier to 139^{o} C above ambient temperature (per ASTM E119 thermal insulation requirement); (b) the exposure time required for the DP-SC component to lose its load carrying capacity due to degradation of material strength at elevated temperature, and (c) the protected liner remains intact to prevent projection of water beyond the unexposed surface during the hose stream test. The LTR states that fire resistance ratings of DP-SC modules may be demonstrated for the design-basis fire using the following methods in ANSI/AISC 360-22, Appendix 4, Section 4.2, as applicable: (a) design by advanced method of analysis (Section 4.2.4c; involving a thermal response and mechanical response); (b) design by simple methods of analysis (Section 4.2.4d); or (c) design by qualification testing using Section 4.3.2g.

The NRC staff finds that the above approach for demonstrating fire resistance rating, under a design-basis fire established by fire hazard analysis, is reasonable for the specific purpose of the performance objective in Section 4.1.1 of ANSI/AISC 360-22, Appendix 4, because it is based on recognized specification for structural steel. However, as stated in Section N4.1 of ANSI/AISC N690-18, "The intended functions of the structure under a design-basis fire shall be stated in the design-basis documents. The provisions of Appendix N4 [Appendix 4 of ANSI/AISC 360-22 as modified] are for life safety associated with evacuation of building occupants in the event of a design basis fire. The Nuclear Specification [ANSI/AISC N690-18, Appendix N4] does not address either "Important to Safety" structural steel members or loading condition associated with a facility fire," which is, therefore, outside the LTR scope (i.e., meeting the fire protection requirements of GDC 3 in Appendix A of 10 CFR Part 50 and 10 CFR 50.48 are outside the scope of the LTR). ***[L & C 8.1(j))***

5.14 Vent Holes Requirements

LTR Section 5.14 states that vent holes are required for concrete-filled steel composite members (including DP-SC walls and slabs) to relieve the buildup of vapor pressure, between faceplates and concrete, caused by water evaporation from heated concrete at elevated temperatures and fire incidents. The NRC staff noted that vent holes are designed using the methodology in AISC Design Guide (DG) 38 (LTR Reference 9-77). The NRC staff also noted that vent hole size and spacing depend on the allowable pressure, concrete moisture content, vent hole spacing, and thermal gradient through member thickness. The LTR lists minimum vent hole requirements for integrated RB DP-SC modules and the required vent hole size for designated effective area is calculated by equating the maximum allowable vapor pressure to maximum allowable hydrostatic pressure on steel plates during concrete casting, calculated using the publication by Bhardwaj et al. (2018, LTR Reference 9-78).

The NRC staff finds the above approach for the design of vent holes for DP-SC modules reasonable because it is based on recognized principles in industry guidance from AISC and supplemented by published literature. However, the NRC staff will review details of vent hole design for the integrated RB structures (including SCCV) DP-SC modules when an application for BWRX-300 SMR is submitted and is included as part of L&C 8.10 in SE Section 5.11.

5.15 Corrosion Protection

The NRC staff reviewed LTR Section 5.15 and noted that corrosion protection for DP-SC modules of integrated RB (including SCCV) will be met for its service life by one (or a combination of) the approaches listed below, will conform to NRC RG 1.54, and will use guidance in ASTM MNL20 (LTR Reference 9-85) for corrosion tests and standards.

- Adding a sacrificial thickness to faceplate thickness as corrosion tolerance not considered for strength or stiffness.

- The use of a Protective Paint System suitable for the surrounding environment per requirements of standards ISO-12944-5 (LTR Reference 9-79) and ANSI/AISC 303 (LTR Reference 9-80), tested to ASTM D1014 (LTR Reference 9-83) procedures, and following best practices and specifications from The Society for Protective Coatings Manual, Volumes 1 and 2 (LTR References 9-81 and 9-82).

- The use of a Membrane Coating System.

- The use of an Impressed Current Cathodic Protection to standard ISO-12473 (LTR Reference 9-84).

The NRC staff finds the above approaches for corrosion protection of DP-SC modules reasonable and acceptable because they are based on cognizant industry standards and best practices for corrosion protection and will conform to the guidance in NRC RG 1.54. While the approaches presented are generally acceptable, the NRC staff imposes a limitation and condition that an applicant referencing the LTR in a license application shall specify details of, and justify adequacy of the selected combination of, corrosion measures that will be implemented for the plant. ***[L&C 8.12]***

5.16 Fabrication and Construction Requirements

The NRC staff noted from LTR Section 5.16 that the ANSI/AISC N690 standard implicitly accounts for effects of locked-in stresses from initial imperfections and hydrostatic pressure during concrete pour through requirements such as minimum faceplate thickness, minimum yield strength, non-slenderness, and non-waviness requirements for faceplates (all addressed in different LTR sections). The staff further noted that fabrication and erection requirements, including dimensional tolerances, for non-containment DP-SC structures will be in accordance with ANSI/AISC N690-18, Chapter NM, which the staff finds acceptable because it is consistent with ANSI/AISC N690-18 as endorsed in RG 1.243.

5.17 Quality Control and Quality Assurance

The NRC staff noted from LTR Section 5.17 that quality control and QA for design, construction, inspection, and testing of BWRX-300 non-containment DP-SC structures will be in accordance with ANSI/AISC N690-18, Sections NA5 and Chapter NN, and NRC RG 1.28, which is consistent with Regulatory Guidance Position C.6 in NRC RG 1.243 (endorses ANSI/AISC N690-18); therefore, the NRC staff finds this approach acceptable to meet the requirements of 10 CFR Part 50, Appendix B, for non-containment DP-SC structures.

5.18 Aging Management, Inservice Inspection, and Testing Requirements for the Integrated Reactor Building

LTR Section 5.18 states that an inservice inspection and testing program is established for the integrated RB DP-SC structures similar to the XI.S6 "Structures Monitoring Program" in NUREG-2191 (GALL-SLR Report) and RG 1.160, and consists of periodic visual inspections of accessible surfaces (i.e., accessible faceplates), and where necessary ultrasonic pulse-echo thickness measurements by qualified personnel at an interval not to exceed 5 years to detect pertinent aging effects such as those described in recognized industry standards such as ACI 349.3R and SEI/ASCE 11 (LTR References 9-87, 9-88). The NRC staff noted that the program may also include requirements for additional examinations for critical components such as below-grade RB exterior wall and mat foundation, and that failure mode effect analysis will be performed to identify aging and degradation mechanisms to detect abnormalities, evaluate inspection results, and propose corrective actions. The NRC staff finds the proposed approach of the fundamental ISI program based on periodic visual examinations of accessible areas to be reasonable and acceptable to identify and manage flaws and aging effects in accessible areas or DP-SC components because it is consistent with typical structures monitoring programs in NRC guidance.

However, the LTR recognizes that other non-destructive examination techniques or methods are necessary to inspect inaccessible steel plates (e.g., back faceplate in below-grade exterior walls) and inaccessible concrete infill for which preservice and inservice visual inspections are not feasible. The NRC staff noted that as demonstrated by testing carried out on DP-SC mockups/prototypes by EPRI as part of the NRIC project (Refer to Enclosure 3 "Demonstration of NDE of Concrete in Mockup and Prototypes" (ML24044A260) docketed by letter, dated February 12, 2024) non-destructive techniques for inservice inspection and testing that may be deployed for the BWRX-300 DP-SC modules include:

- Use of ultrasonic sensors in concrete infill that enable determining relative changes of ultrasonic wave velocity that could indicate if a concrete defect is present or use windows of exposed concrete for examination.

- Use of ultrasonic guided wave phased array (screening of defects within steel plates).

- Use of high-energy x-ray (location of voids and foreign material within concrete).

- Use of low-frequency ultrasound (evaluation of steel-plate contact and defects within the concrete).

GEH also indicted that additional methods may be implemented after further evaluation during detailed design. The NRC staff noted that baseline preservice examination data will be established by testing during construction, including nondestructive examination (NDE) measurements for methods identified as part of the ISI or aging management program, for trending analysis in subsequent inspections. The NRC staff also noted that measured baseline data of material properties and other parameters will be established by testing as part of Certified Material Test Report, which the NRC staff finds acceptable because the baseline data facilitates future evaluation, monitoring, and trending of applicable aging effects, including irradiation embrittlement, for the DP-SC modules during its service life.

However, the NRC staff finds the need for a limitation and condition as follows. While LTR Section 5.18 discusses several potential NDE techniques or approaches that may be used for inspection and NDE/testing of inaccessible DP-SC areas or components, an applicant referencing the LTR in a future application shall submit for NRC staff review a plant-specific program consisting of the specific NDE methods that will be implemented in addition to visual examinations for preservice and inservice inspection of the inaccessible DP-SC integrated RB components, including concrete infill. An applicant may additionally consider including a provision to evaluate the acceptability of inaccessible areas or components of the DP-SC modules when conditions exist (or are found) in accessible areas that could indicate the presence of, or could result, in flaws or degradation in such inaccessible areas. ***[L&C 8.13]***

6.0 TECHNICAL EVALUATION: PROPOSED DESIGN APPROACH FOR BWRX-300 STEEL-PLATE COMPOSITE CONTAINMENT VESSEL [USING DP-SC MODULES]

6.1 Introduction

LTR Section 6.0 provides the proposed approach for materials, design, fabrication, construction, examination and testing of the BWRX-300 DP-SC SCCV structure by adapting the provisions of CC-2000 through CC-6000 of 2021 ASME Code III-2, as applicable (provisions involving reinforcing steel or tendons are generally not applicable) and/or modified and supplemented for DP-SC modules. The LTR considers the SCCV as equivalent to a ASME III-2 Class CC containment and the boundary jurisdiction of the DP-SC SCCV is as shaded in green in LTR Figure 4-1 (proprietary). The SCCV DP-SC module pressure-retaining/resisting boundary components include the inner and outer faceplates (noting only the inner faceplate is credited as a leak-tight barrier to which liner leak-tightness requirements apply), diaphragm plates, steel headed stud anchors, and concrete infill. DP-SC module design parameters for SCCV are the same as in LTR Section 5.1 and evaluated in SE Section 5.1. The NRC staff notes that the 2019 ASME Code III-2 is endorsed with conditions in NRC RG 1.136, Revision 4, and the changes in the 2021 edition are generally editorial or improvements. The NRC staff also notes that the design approach for the DP-SC presented in LTR Section 6.0 is consistent with the allowable stress design philosophy of ASME Code III-2 (versus the LRFD design philosophy used in LTR Section 5.0 for non-containment DP-SC structures.

6.2 Materials

LTR Section 6.2.1 states the use of self-consolidating concrete as concrete infill meets the requirements of CC-2200 “Concrete and Concrete Constituents” of ASME Code III-2 with modifications of aggregate size, limit on chloride content to minimize possibility of corrosion. The NRC staff finds the use of SCC as concrete infill reasonable for DP-SC based on its evaluation and upper limit concrete strength in SE Section 5.2.

LTR Section 6.2.2 states that steel materials for DP-SC faceplates and diaphragm plates meet the requirements of CC-2500 “Material for Liners” of ASME Code III-2 for containment liners, and note that elevated temperature-dependent mechanical properties of steel materials used will be determined in accordance with ASME Code, Section II, Part D. The NRC staff finds the requirements for DP-SC SCCV steel materials based on CC-2500 to be appropriate and acceptable within the yield strength range (50 ksi – 65 ksi) in LTR Section 5.2.2 because its use is endorsed in RG 1.136 for concrete containment which remains applicable for SCCV, and on the basis of the NRC staff evaluation of DP-SC steel materials and permitted yield strength range (50 ksi – 65 ksi) in SE Section 5.2.

LTR Section 6.2.3 states all welding materials conform to the requirements of CC-2600 “Welding Material” of ASME Code III-2, which the NRC staff finds acceptable because the proposed use of weld materials is endorsed in NRC RG 1.136 for concrete containment which remains applicable for DP-SC SCCV.

LTR Section 6.2.4 states that if used, load bearing steel materials (e.g., embedment anchors used to support attachments to faceplates or stiffeners in connection areas) will meet requirements of CC-2700 “Materials for Embedment Anchors.” The NRC staff finds this acceptable because the proposed use of embedment anchor materials is endorsed in RG 1.136 for concrete containment which remains applicable for DP-SC SCCV.

6.3 Effective Stiffness, Geometric and Material Properties of Diaphragm Plate Steel-Plate Composite Modules for Finite Element Analysis

LTR Section 6.3 states that effective stiffness, geometric and material properties used for FE analysis of DP-SC SCCV elements for operating and accident conditions are computed per LTR Section 5.5; therefore, refer to SE Section 5.5 for the corresponding NRC staff evaluation.

6.4 Damping Values

Refer to SE Section 5.5.2 for NRC staff evaluation of damping values.

6.5 Design Loads and Load Combinations for Steel-Plate Composite Containment Vessel

LTR Section 6.5 notes that the loading criteria and load combination provisions of CC-3200 of ASME Code III-2, as supplemented by RG 1.136, are applicable and followed in the analysis of the SCCV structure. The staff finds this acceptable because the loads and load combinations in CC-3200 for concrete containments are applicable to DP-SC containment and are used in the LTR as endorsed in RG 1.136.

6.5.1 Structural Thermal Analysis

From LTR Section 6.5.1, the NRC staff noted **[[**

]] As stated in LTR Section 6.2.2, which is evaluated in SE Section 6.2.2, elevated temperature-dependent mechanical properties of steel materials used will be determined in accordance with ASME Code, Section II, Part D.

The NRC staff finds that the proposed **[[**

]] and is required to account for time lag effects between concrete and steel materials, for use in the DP-SC SCCV FE analysis for accident thermal conditions, and therefore acceptable. The NRC staff also finds it acceptable that concrete temperatures will be **[[**
]] because the code provision is endorsed in RG 1.136 for the same material in concrete containments. Also, refer to the SE Section 5.5.1.

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6.6 Design Allowable Limits and Acceptance Criteria for Steel-Plate Composite Containment Vessel

The NRC staff reviewed LTR Section 6.6 and noted that the modified (to include steel plates) acceptance criteria for DP-SC concrete and steel plates in the form of allowable stress/strain limits for factored loads and allowable stress for service loads, presented in LTR Tables 6-1 (a) and 6-1(b), respectively, are consistent with the corresponding allowable limits for concrete compression in Figures CC-3421-1 and CC-3422-2, and for steel plates consistent with the allowable limits for steel reinforcement in CC-3422 and CC-3432 for each of the force classifications (primary, primary + secondary; membrane, membrane + bending). The staff further notes that this approach is also consistent with the design philosophy in ASME Code III-2 which **[[**

]] The NRC staff finds this approach for acceptance criteria for DP-SC acceptable because the acceptance criteria (design allowable stresses) for concrete and steel plates are consistent with that for concrete and reinforcing steel in ASME Code III-2 for each of the force classifications, and as endorsed in NRC RG 1.136.

6.7 Required Strength (Demand) Calculations

The NRC staff noted from LTR Section 6.7 that SCCV demands under design loads and combinations are obtained from linear elastic FE analysis discussed in LTR Section 4.0, Further, **[[**

]]

For the steel plates, **[[**

]] and shown to be less than or equal to the allowable stresses for steel plates in LTR Table 6-1(a) and 6-1(b), respectively, for factored and service loads.

For concrete infill, **[[**

]] and shown to be less than or equal to the allowable stresses for concrete in LTR Table 6-1(a) and 6-1(b), respectively, for factored and service loads.

The NRC staff finds the above approach to perform stress checks for the SCCV reasonable and acceptable because the methodology is conservative and equations for calculating demand stresses is based on principles of engineering mechanics and theory of elasticity, and the publication by **[[ ]]**

6.8 Section Capacities of Steel-Plate Composite Elements

LTR Section 6.8 presents the methodology out-of-plane shear and interaction checks for the SCCV.

6.8.1 One-Way Out-of-Plane Shear Strength

From LTR Section 6.8.1, the NRC staff noted that, for factored loads, out-of-plane shear checks are performed by showing the shear demand is not greater than the ***design*** out-of-plane shear strength or capacity determined by LTR Equation [5-25] with the nominal capacity computed using LTR Sections 5.7.5.1 or 5.7.5.2, as applicable. For service loads, the same check is performed with the ***nominal*** out-of-plane shear capacity computed using LTR Sections 5.7.5.1 or 5.7.5.2 reduced to 50 percent or 67 percent for different load conditions (primary, pressure, secondary). These reductions are consistent with CC-3431.3 of ASME Code III-2 for shear, and therefore acceptable because ASME Code III-2 is endorsed by RG 1.136. For NRC staff evaluation of LTR Sections 5.7.5.1 and 5.7.5.2, refer to SE Section 5.7.5.

6.8.2 Two-Way (Punching) Shear Strength

From LTR Section 6.8.2, the NRC staff noted that, for factored loads, two-way (punching) shear checks are performed by showing that the punching shear demand is not greater than the ***design*** out-of-plane shear strength or capacity determined as described in LTR Sections 5.7.5.3. For service loads, the same check is performed with the ***nominal*** punching shear capacity computed using LTR Section 5.7.5.3 reduced to 50 percent or 67 percent for different load conditions (primary, pressure, secondary). These reductions are consistent with CC-3431.3 of ASME Code III-2 for shear and are therefore acceptable because it is endorsed by RG 1.136. For NRC staff evaluation of LTR Section 5.7.5.3, refer to SE Section 5.7.5.

6.8.3 Out-of-Plane Shear Interaction Checks

From LTR Section 6.8.3, the NRC staff noted that out-of-plane shear interaction checks are performed as described in LTR Section 5.7.6 using LTR Equation [5-34] as-is for factored loads, and for service loads the values of V_c and $V_{conc,}$ in Equation [5-34 and NOT 5-32] as defined in LTR Section 5.7.6 are reduced to 50 percent or 67 percent for different load conditions (primary, pressure, secondary). These reductions are consistent with CC-3431.3 of ASME Code III-2 for shear, and therefore acceptable because ASME Code III-2 is endorsed by RG 1.136. For NRC staff evaluation of LTR Section 5.7.6, refer to SE Section 5.7.6.

6.9 Allowable Bearing Stress of Containment Steel-Plate Composite elements

The NRC staff noted from LTR Section 6.9 that the allowable (maximum) bearing stress in concrete for DP-SC elements are in accordance with CC-3421.9 of ASME Code III-2 for factored loads, and in accordance with CC-3431.3 of ASME Code III-2 for service loads. The NRC staff finds this acceptable because it is consistent with ASME Code III-2, which is endorsed in RG 1.136.

6.10 Impulsive and Impactive Design

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The staff noted from LTR Section 6.10 that the SCCV is designed for impact and impulsive loads using the guidance in Appendix A of NUREG-0800, SRP Section 3.8.1; and that the shear and deformation requirements are described in LTR Section 5.8. The NRC staff finds this approach reasonable since it is based on SRP guidance for impactive and impulsive loads associated with DBAs, and the LTR Section 5.8 provisions evaluated in SE Section 5.8. However, the NRC staff will perform a detailed review of the specifics of the SCCV design for impact and impulsive loads when an application for BWRX-300 SMR is submitted. ***(See L&C 8.7 in SE Section 5.8)***

6.11 Design of Brackets and Attachments

LTR Section 6.11 notes that steel brackets and attachments connected to the SCCV structure are analyzed and designed using accepted techniques applicable to beams, columns, and weldments such as illustrated in ANSI/AISC N690-18 and ANSI/AISC 360-16 standards. The NRC staff finds this acceptable because bracket and attachments will be designed to recognized standards endorsed by the NRC in RG 1.243, which is also consistent with the approach in CC-3750 of ASME III-2.

6.12 Design and Detailing of Penetrations and Openings

The LTR states that SCCV penetrations and openings meet the requirements of CC-3740 of ASME Code III-2, to the extent applicable to DP-SC. Furthermore, the design and detailing of large openings and a bank of small openings are in accordance with ANSI/AISC N690, Appendix N9 “SC Walls,” Section N9.1.7b and Section N9.1.7c, respectively.

The NRC staff finds the approach for design and detailing of DP-SC SCCV penetrations and openings acceptable because they are based on provisions from applicable codes and standards endorsed by the NRC in RG 1.136 and 1.243.

6.13 Welded Construction of Diaphragm Plate Steel-Plate Composite Containment

LTR Section 6.13 illustrates in Figure 6-2 (proprietary) and describes Typical Welded Joint Locations for all Joint Categories and in Table 6-2 (proprietary) defines each Weld Joint Category and describes for each category the permissible types of welded joints and rules for making welded joints, and the required examination of welds for the DP-SC SCCV. Also, Figure 6-3 (proprietary) provides Typical DP-SC Welded Joint Details.

The NRC staff finds that the joint category descriptions and illustrations, permissible weld types of weld joints, and the required weld examinations are **[[**

]] Based on the above, the staff finds the weld joint category requirements proposed in LTR Section 6.13 are reasonable and appropriate for DP-SC SCCV.

6.14 Design of Steel-Plate Composite Connections

The NRC staff noted from LTR Section 6.14 that the requirements of ANSI/ASIC N690-18, Appendix N9, Section 9.4 are adapted, as described in LTR Section 5.11, to the design of the SCCV splices, slab-to-wall, and wall-to-mat foundation connections. Refer to the NRC staff evaluation in SE Section 5.11.

6.15 Fabrication and Construction Requirements

LTR Section 6.15 states fabrication and construction requirements for SCCV DP-SC modules are in accordance with CC-4000 of ASME Code III-2, in addition to Regulatory Position 10 in RG 1.136, to the extent applicable to DP-SC modules without reinforcing steel or tendons. The LTR notes that leak-tightness requirements are only applicable to the inner faceplate, which is only credited to serve as a leak-barrier. The LTR identifies specific sections of CC-4000 that are not applicable to fabrication and construction of DP-SC with the reason for non-applicability. The LTR also specified certain amended requirements to CC-4000 to adapt them to DP-SC modules. The LTR also includes certain additional requirements established for DP-SC SCCV. Based on response to Question 9 (RAI 6.13-1) by letter, dated March 14, the NRC staff noted that GEH provided a comparative evaluation that concluded that ASME Code III-2 CC-4530 and CC-4540 requirements for the liner are adequate for welding qualifications and the rules governing the making of welds for DP-SC SCCV and equivalent to those of ASME Code III-1, NE-4300, and NE-4400 for Class MC containments.

The NRC staff finds that the proposed use of requirements in CC-4000 of ASME III-2, as applicable and adapted for DP-SC, for fabrication and construction of DP-SC SCCV is reasonable, and the additional requirements would help assure a quality product, and therefore is acceptable.

6.16 Construction Testing and Examination Requirements, Including Weld Examination and Qualification for Diaphragm Plate Steel-Plate Composite Modules

LTR Section 6.16 states that construction testing and examination of materials (concrete, steel) and welds, and qualification of examination personnel of SCCV DP-SC components will follow the requirements of Article CC-5000 of the ASME Code III-2, where applicable. Concrete and its constituents are examined and tested in accordance with Subarticle CC-5200, with modifications that include (a) the use of non-destructive testing techniques described in LTR Section 5.18 to detect hidden defects, honeycombing, and voids since concrete in DP-SC modules are not accessible for visual examination; (b) the use of embedded cameras left in place to monitor concrete placement in congested areas to assess concrete flow/consolidation, or alternately testing of mockup specimens per CC-4226.3; and (c) additional concrete sampling requirements provided in Section 3.2.2.1 of NRC-approved LTR NEDO-33914-A to address the effect of small volume of concrete placed for BWRX-300.

Further, the LTR proposed weld examination per Subarticle CC-5500, considering modifications that include (a) use magnetic particle or ultrasonic examination of the full length of the weld (as allowed by CC-5521) where radiographic examination is required and the joint detail does not permit examination; (b) leak-testing required by CC-5521(e) and described in CC-5536 is limited to inner faceplate welds (which is only credited as a leak-barrier) and is required to be performed prior to concrete infill placement; and (c) required examination of different weld categories shall follow requirements in LTR Table 6-2 instead of CC-5521.

The NRC staff finds that the requirements of CC-5000, as adapted, and proposed modifications for testing and examination of SCCV materials (concrete, steel) and welds are reasonable, and in general follow requirements in a recognized standard. However, the NRC staff will perform a detailed review of construction examination and testing requirements, including specific non-destructive testing of concrete, when a future license application is submitted for the BWRX-300 SMR.

6.17 <u>Steel-Plate Composite Containment Vessel Preservice Inspection and Testing Requirements</u>

LTR Section 6.17 states that a preservice structural integrity test (SIT) and associated inspection of the SCCV will be conducted following the requirements of Article CC-6000 "Structural Integrity Test of Concrete Containments" in ASME Code III-2, to the extent they apply to DP-SC modules without reinforcing steel or tendons and considering that leak tightness requirements related to liners of concrete containments is applicable only to the inner faceplate of the DP-SC SCCV. The LTR identifies the specific sections of Article CC-6000 related to the SIT with regard to visual inspection, observations, crack mapping and measurements of concrete that are not applicable to the SCCV since concrete is inaccessible for the constructed DP-SC SCCV. SCCV structural integrity is verified in the SIT by comparing displacement measurements to analytical model predictions (per CC-6160, CC-6510). Furthermore, faceplate strain measurements are compared to analytical model predictions for only the prototype containment (i.e., per CC-6150, the first tested BWRX-300 unit). Tests are also performed, per CC-4226.3, on representative DP-SC mockup specimens filled with specified concrete to confirm and demonstrate adequate placement and consolidation of concrete in the DP-SC modules.

The NRC staff finds the proposed CC-6000 preservice SIT, conducted at 1.15 times the design pressure, reasonable and very important to provide an adequate verification and validation of the quality of construction and acceptable structural performance of the new design features of the as-constructed DP-SC SCCV, and the representative mockup tests are reasonable to demonstrate adequate placement/ and consolidation of the specified concrete for DP-SC SCCV because they are based on CC-6000 and CC-4000 requirements as applicable to DP-SC, respectively, of the ASME Code III-2, endorsed in NRC RG 1.136. Further, the pre-operational integrated leak rate test at DBA pressure, required by 10 CFR Part 50, Appendix J, will provide verification and validation of the leak-tight integrity of the as-constructed SCCV.

6.18 <u>Effect of Curvature on Behavior of Steel-Plate Composite Containment Vessel</u>

LTR Section 6.18 states that SCCV wall curvature is included in the integrated RB FE model. The NRC staff evaluation of curvature effects in SE Section 5.12 also applies to SCCV (including the associated L&C). Additionally, the LTR states rolling and bending shall follow the fabrication requirements in CC-4521 of ASME III-2 code, which the NRC staff has endorsed in RG 1.136 and finds acceptable.

6.19 <u>Corrosion Protection of Diaphragm Plate Steel-Plate Composite Modules</u>

Refer to SE Section 5.15 (including the associated L&C) for NRC staff evaluation of corrosion protection, which also applies to the SCCV.

6.20 <u>Fire Resistance of Diaphragm Plate Steel-Plate Composite Modules</u>

LTR Section 6.20 states the SCCV is designed to have a 3-hour fire resistance rating. Refer to SE Section 5.13 (including the associated L&C) for NRC staff evaluation of design and evaluation criteria for fire protection which also applies to SCCV.

6.21 Vent Hole Requirements

The NRC staff evaluation of vent hole requirements in SE Section 5.14 also applies to SCCV. Additionally, LTR Section 6.21 identifies exceptions that SCCV vent holes are only used in the external faceplate of walls and slabs except for external faceplates facing soil, and also not allowed on the internal faceplates which provides the leak-barrier. The NRC staff finds these exceptions for use of vent holes reasonable because they ensure vent holes are not used on faceplates that provide leak-tightness or may be exposed to an aggressive environment.

6.22 Steel-Plate Composite Containment Vessel Inservice Inspection and Testing Requirements

LTR Section 6.22 describes an approach for establishing a preservice and periodic inservice inspection [and testing] program for the BWRX-300 DP-SC SCCV to meet the requirements of 10 CFR 50.55a(g) by adapting the provisions of the ASME Code, Section XI, Subsection IWE and Subsection IWL, incorporated by reference in 10 CFR 50.55a. The LTR states that DP-SC SCCV pressure boundary metallic components, namely, the inner and outer faceplates (while both faceplates are strength elements, only the inner faceplate acts as leak-tight barrier), diaphragm plates, headed stud anchors and welds shall meet the ISI and repair/replacement requirements applicable to Class MC pressure-retaining components and their integral attachment of Subsection IWE. Furthermore, the DP-SC SCCV concrete infill shall meet the ISI and repair/replacement requirements of Subsection IWL. The LTR notes that the diaphragm plates, headed stud anchors, embedments, and their welds, as well as the concrete infill are inaccessible for inspection in the constructed SCCV, and therefore exempted from ISI visual examination. The LTR provides considerations (what can or may be done but not what will be done) for ISI of SCCV concrete infill, which include acoustic emission monitoring, use of NDE techniques described in LTR Section 5.18, and testing mockup specimens exposed to similar conditions.

The NRC staff finds the approach for preservice and inservice inspection of the SCCV pressure boundary by adapting requirements of ASME Section XI, Subsection IWE and IWL, as applicable to DP-SC, reasonable because it is based on ISI standard incorporated by reference, with conditions, in 10 CFR 50.55a regulation, and the other considerations appear reasonable. However, an applicant referencing the LTR shall submit for NRC staff review a plant-specific program that includes specific considerations and NDE methods that will be implemented for preservice and inservice inspection of inaccessible DP-SC SCCV components, including concrete infill. ***[L&C 8.14]***

6.23 SCCV Beyond Design-Basis Evaluation

6.23.1 Ultimate Pressure Capacity of Steel-Plate Composite Containment Vessel

The NRC staff noted from LTR Section 6.23.1 that for prediction of SCCV internal pressure capacity to establish safety margin as required by GDC 50, **[[**

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The NRC staff finds this approach to estimate the SCCV ultimate pressure capacity acceptable because it is based on the guidance in Regulatory Position 1 of NRC RG 1.216 (LTR Reference 9-32) for reinforced concrete containments which is reasonable for the DP-SCCV based on expected similarity of behavior under accident pressure and conservative compared to the criteria in RG 1.216 for steel containments.

6.23.2 Steel-Plate Composite Containment Vessel Robustness Against Combustible Gas Pressure Loads

LTR Section 6.23.2 describes the approach that will be used to demonstrate containment structural integrity as required by 10 CFR 50.44(c)(5) for combustible gas control inside containment. The LTR states that **[[**

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The NRC staff reviewed the above approach against the criteria in the applicable Regulatory Position 2 “Combustible Gas Control Inside Containment” of RG 1.216, and finds it generally consistent with the following exception:

The LTR acceptance criteria does not meet the criteria in Regulatory Position 2.c in NRC RG 1.216 (based on Regulatory Position 5 of NRC RG 1.7) which states that for the required pressure and dead load, “for concrete containments, the acceptance criteria are limited to demonstrating that the liner strains satisfy the Factor Load Category requirements presented in ASME Code, Section III, Division 2, Subarticle CC-3720,” in that the liner strain allowable for Factored Category in CC-3270, Table CC-3720-1, includes separate strain criteria for “membrane” and “combined membrane and bending” both of which must be met for compression and/or tension strain, applicable to the loading condition. However, the LTR description only includes “combined membrane and bending” criteria and limited to tension. Therefore, to find the approach acceptable, the NRC staff imposes a related limitation and condition as above. ***[L&C 8.15]***

6.23.3 Steel-Plate Composite Containment Vessel Behavior Following a Severe Accident

LTR Sections 6.23.3.1 and 6.23.3.2 describes GEH’s proposed approach for evaluations of SCCV following a severe accident for (a) the 24-hour period following the onset of core damage; and (b) the period following initial 24 hours after the onset of core damage. The LTR states the

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SCCV robustness is evaluated **[[**

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The NRC staff finds the approach proposed in the LTR reasonable because it follows the guidance in Regulatory Position 3 of NRC RG 1.216.

7.0 TECHNICAL EVALUATION: NRIC DEMONSTRATION PROJECT OVERVIEW

LTR Section 7.0 provides a summary of the confirmatory prototype tests and results conducted at Purdue University under the NRIC Demonstration Project Phase 1: Detailed Design and Structural Performance Testing. The detailed description of the tests and results are provided in the document GEH ID:007N0873, Revision 2, NRIC Prototype Test Report (ML23212B129 – proprietary; ML23212B131 – non-proprietary). The NRC staff noted that the confirmatory prototype tests were performed on structural scaled specimens made of a commercially manufactured Steel Bricks™ representing DP-SC modules.

The NRC staff noted the objectives of the confirmatory NRIC Phase 1 prototype tests were to evaluate the performance of DP-SC modules for various loading conditions applicable for containment (i.e., pressure-retaining) and non-containment applications. A total of 14 Steel Bricks™ scaled prototype specimens were designed, constructed, and tested to be representative of DP-SC integrated RB components as follows:

1) Out-Of-Plane Shear (Mat foundation; (2) 1:2 scale specimens OOPV-1, OOPV-2)

2) Bi-Axial Tension (SCCV wall; (3) 1:3 scale specimens BA-1-AMB, BA-1-TH, BA-2-TH)

3) In-Plane Shear (SCCV wall-to-mat foundation connection; (2) 1:3 scale specimens IPV-1, IPV-2)

4) In-Plane Shear + Out-Of-Plane Shear (RB exterior wall-to-mat foundation connection; (2) 1:3 scale specimens IPV+OOPV-1, IPV+OOPV-2)

5) Missile Impact (RB wall; (5) 1:6 scale specimens IMP-D-1, IMP-D-2, IMP-C-3, IMP-C-4, IMP-C-5)

The NRC staff also noted the NRIC prototype test results are to confirm and support: (a) applicability of ANSI/AISC N690-18, Appendix N9 capacity (strength) equations with modifications in LTR Section 5.0 for the design and construction of integrated RB DP-SC modular structures, and (b) applicability of the proposed design approach presented in Section 6.0 for the design and construction of DP-SC containment structures (SCCV).

The NRC staff noted that the prototype test specimens are scaled (i.e., geometric size) to facilitate testing using the existing loading assemblies available at the test laboratory. All test specimen geometric properties are scaled based on DP-SC section sizes and steel-plate thicknesses comparable to the conceptual design section properties of the BWRX-300 full-scale integrated RB structures. SCC was used as concrete infill in the NRIC Phase 1 testing

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specimens. GEH concluded that the NRIC confirmatory test conclusions are directly applicable to the BWRX-300 integrated RB design.

The NRC staff further noted that specimens are approximately 1:2, 1:3, or 1:6 scale depending on the loading and estimated capacity. Pre-test calculations and numerical simulations using FE analysis were performed to calculate the capacities of the specimens and ensure they were within the limits of the testing apparatus. These calculations were based on ANSI/AISC N690 code provisions, with modifications as applicable. Measured material properties taken directly from material test reports, which are usually higher than the specified minimum code/standard properties, were used in the pre-test calculations to provide predictions of the expected specimen capacities ($\phi R_{n\text{-}meas}$) for Criterion A. However, the acceptance criteria for design are based on the nominal capacities ($R_{n\text{-}nom}$) calculated based on specified minimum steel and concrete material strengths without the resistance factor and compared with experimental results (Criterion B). Nevertheless, LTR Table 7-2 documented the results using both criteria, namely, Criterion A: $R_{exp}/R_{n\_nom} \geq 1$ and Criterion B: $R_{exp}/(\phi R_{n\text{-}meas}) \geq 1$.

The LTR also states that NEDO-11209-A, GEH QA program, was implemented during the testing program which was performed using a graded approach to fabrication and testing activities. GEH inspection reports demonstrating procurement and manufacturing traceability, and GEH witness test reports were documented. The testing plan and results were reviewed and accepted by GEH per NEDO-11209-A.

LTR Figures 7-1 through 7-6 illustrate the different test specimen configurations for the testing. LTR Table 7-1 summarizes the different DP-SC module NRIC Prototype tests performed with the test objectives, loading type/orientation and test specimen designation and scale for each test. LTR Sections 7.2.2 through 7.2.6 summarize the test details and acceptance criteria for the 5 prototypes (listed above) tested, and the corresponding test results are summarized in LTR Section 7.3. The NRC staff noted from LTR section 7.3 that the test specimens exhibited generally ductile behavior under load. The NRC staff noted from LTR Tables 7-2 and 7-3, all the test specimens met both the acceptance criteria (A) and (B), with margin indicating the design equations are conservative. The limiting acceptance criteria ratio for Criterion (A) were in the range 1.11 (biaxial tension tests) to 1.45 (out-of-plane flexure, OOPV-2); and for design Criterion (B) were in the range 1.24 (biaxial tension tests) to 1.74 (out-of-plane flexure). The NRC staff also noted that the missile impact test results with missile stopped in 4 of the 5 tests in a bulging damage mode are confirmatory of the impact resistance of DP-SC modules, indicating additional impact resistance provided by the diaphragm plate, and that the modified design method (using LTR Reference 9-69) appears conservative when applied to the NRIC specimens.

Based on its review of LTR Sections 7.2 and 7.3 and the NRIC Prototype Test Report, the NRC staff finds that the geometrically scaled NRIC Prototype Testing specimens were of sufficient size to be reasonably representative of the materials and geometric configuration of the integrated RB DP-SC components, testing was conducted to an adequate quality program for research and development, observed specimen structural behavior was generally ductile which scales well, and the results indicate that the test objectives and acceptance criteria were met with margin for each of the prototype tests; therefore, the data and results provide a reasonable confirmation of the equations used in the methodologies presented in LTR Sections for the BWRX-300 integrated RB structures (including SCCV) using DP-SC modules.

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8.0 LIMITATIONS AND CONDITIONS

An applicant may reference the design-specific LTR for use as applied to the applicant's facility in a BWRX-300 SMR license application only if the applicant demonstrates compliance with the following limitations and conditions or provide additional justification for any deviations.

8.1 Outside-of-Scope: The following structures, components, functional and design aspects (and any other explicitly stated in the LTR) are outside the scope of this LTR:

(a) Overpressure protection of the SCCV (CC-7000 of ASME Section III, Division 2 not adapted; LTR Section 1.1 and 6.0)

(b) Radiation shielding function design requirements (LTR Section 1.2)

(c) LTR Sections 2.4 and 2.5 address regulatory requirements under the jurisdiction of the CNSC and therefore outside of the NRC review scope. (SE Section 2.3)

(d) The RPV, Class MC closure head and other Class MC metal components of the SCCV not backed by concrete at the pressure boundary, including personnel/equipment/access hatches, and mechanical and electrical penetrations, constructed to ASME Section III, Division 1 (SE Section 3.1; LTR Sections 3.3 and 4.0).

(e) Steel containment internal structures, containment equipment and piping support structure (CEPSS), and the bioshield wall constructed to ANSI/AISC N690-18 (SE Section 3.1; LTR Section 3.3 and LTR Figure 4-1)

(f) DP-SC Module configurations different from those described and illustrated in Section 3.4 (SE Section 3.2)

(g) While the LTR states BWRX-300 Integrated RB design will comply with the requirements of 10 CFR 50.150 "Aircraft impact assessment" using applicable regulatory guidance (e.g., RG 1.217), specific requirements and approaches (i.e., detailed methodology) for beyond-design-basis aircraft impact explicit dynamic analyses are outside the scope of the LTR (SE Sections 2.3 and 5.8.4; LTR Sections 2.1.1.5, 2.2.7, 2.3.11 and 5.8.4)

(h) Evaluations and criteria for design extension events Tier 2 (DEE-2) as defined in IAEA Safety Report 87 and corresponding severe damage criteria in LTR Table 5-2 are beyond the scope of NRC regulations and regulatory guidance cited in LTR Section 2.0, and therefore outside the scope of this LTR. (SE Section 5.8.1.3; LTR Section 5.8.1.3, Table 5-2)

(i) Plant-specific probabilistic risk assessment and severe accident evaluations, including seismic margins assessment, will be addressed in each plant-specific FSAR, and outside the scope of the LTR; however, methodology used to evaluate SCCV ultimate pressure capacity, robustness against combustible gas pressure loads, and behavior following a severe accident described in LTR Section 6.23 are within LTR scope. (SE Section 2.2; LTR Section 2.2.7)

(j) Regarding LTR Section 5.13, as stated in Section N4.1 of ANSI/AISC N690-18, “The intended functions of the structure under a design basis fire shall be stated in the design basis documents. The provisions of Appendix N4 [Appendix 4 of ANSI/AISC 360-22 as modified] are for life safety associated with evacuation of building occupants in the event of a design basis fire. The Nuclear Specification [ANSI/AISC N690-18, Appendix N4] does not address either “Important to Safety” structural steel members or loading condition associated with a facility fire;” which therefore, is outside the LTR scope (i.e., meeting the fire protection requirements of GDC 3 in Appendix A of 10 CFR Part 50 and 10 CFR 50.48 are outside the scope of the LTR). (SE Sections 5.13 and 6.20; LTR Sections 5.13 and 6.20)

8.2 Regarding footnote (1) in LTR Section 5.1, the NRC staff review and approval of the LTR is based on equations presented in the LTR Sections 5.0 and 6.0, and consistent with the confirmatory NRIC Prototype Testing. If the equations are modified for use of different plate thickness or material yield strength (within bounds in LTR Section 5.2.2) between faceplates and diaphragm plates, the modified equations and supporting derivation shall be submitted for NRC staff review as part of a future application referencing the LTR. It is further clarified that if the equations are modified, the thickness and material yield strength of the inner faceplate and the outer faceplate shall remain the same. (SE Section 5.1; LTR Sections 5.1 and 5.2.2)

8.3 DP-SC Section thickness or depth (t_{sc}) greater than 60 inches is not permitted consistent with AISC N690-18, Appendix N9, endorsed in RG 1.243. (SE Section 5.1; LTR Section 5.1).

8.4 The upper bound (maximum) concrete compressive strength (f’c) for concrete infill based on the equations [5-1] in LTR Section 5.2.1 shall be limited to 8 ksi (55 MPa) and not 10 ksi (70 MPa). (SE Section 5.2; LTR Section 5.2.1)

8.5 The use of public review draft of the next edition of ANSI/AISC N690-XX on a limited basis in the LTR shall not in any way be construed as NRC endorsement of Draft AISC N690-XX. until after formal staff’s endorsement of the published next edition. (SE Sections 5.3 and 5.4; LTR Sections 5.3 and 5.4)

8.6 In LTR Section 5.7.2, **[[**

]] (SE Section 5.7.2; LTR Sections 5.7.2)

8.7 (a) In LTR Section 5.8.1.3, Table 5-2, the allowable ductility ratio for in-plane shear (shear walls) shall be limited to 1.5 (and not 3.0) consistent with Table 14 of referenced IAEA SR No.87; (b) Also, the statement in the second bullet of LTR Section 5.8.1.3 for DP-SC containment under DBAs is further clarified that: For normal and severe environmental load categories, the allowable limits for ductility, support rotation, and strain shall not exceed those for superficial damage in LTR Tables 5-2 and 5-3; and, for abnormal, extreme environmental, and abnormal and extreme environmental load categories, the allowable limits for ductility, support rotation, and strain shall not exceed

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those for limited damage in LTR Tables 5-2 and 5-3; (c) Additionally, for flexure-controlled DP-SC components, in accordance with Footnote (2) to LTR Table 5-2, and regulatory position C 11.1.4 in RG 1.243, the criteria in terms of support rotations from Table 5-2, in terms of ductility from LTR Table 5-2 and in terms of strains from LTR Table 5-3 shall all be met to control damage. (SE Sections 5.8.1.3, 5.8.3, and 6.10; LTR Sections 5.8.1.3, 5.8.3, 6.10 and LTR Table 5-2)

8.8 LTR Section 5.11 states **[[**

]] If the higher concrete contribution stated above is used, the recommended supporting technical basis with peer review shall be submitted for NRC staff review as part of a future application referencing the LTR. (SE Section 5.11; LTR Section 5.11)

8.9 With reference to LTR Section 5.11, transfer of forces and moments (for e.g., horizontal reaction) from the DP-SC RB roof to the DP-SC RB cylindrical wall and related connections, which are not addressed in the LTR, shall be addressed in detailed design, and made available for NRC staff review as part of a future application referencing the LTR. (SE Sections 5.11 and 6.14; LTR Sections 5.11 and 6.14)

8.10 With reference to LTR Section 5.11, design implementation of connections between DP-SC slabs (including basemat) and DP-SC walls, DP-SC wall-to-wall, and splices and ventholes of DP-SC modules shall be addressed in detailed design and made available for NRC staff review as part of a future application referencing the LTR. (SE Sections 5.11, 5.14, 6.14, and 6.21; LTR Sections 5.11, 5.14, 6.14, and 6.21)

8.11 With reference to LTR Section 5.12, the integrated RB curved DP-SC walls (including SCCV walls) shall be designed and detailed to have a radius of curvature-to-wall panel thickness greater than 2.0 without exception. Further, any residual stresses and strains resulting from rolling of the curved plates shall be evaluated and incorporated in detailed design. (SE Sections 5.12 and 6.18; LTR Sections 5.12 and 6.18)

8.12 While the approaches presented in LTR Section 5.15 for corrosion protection of DP-SC modules are generally reasonable, an applicant referencing the LTR in a future license application shall specify details of and justify adequacy of the selected combination of corrosion measures that will be implemented for the plant. (SE Sections 5.15 and 6.19; LTR Sections 5.15 and 6.19)

8.13 While LTR Section 5.18 discusses several reasonable potential non-destructive examination techniques or approaches that may be used for inspection and NDE/testing of inaccessible DP-SC areas or components, an applicant referencing the LTR in a future application shall submit for NRC staff review a plant-specific program consisting of the specific NDE methods that will be implemented in addition to visual examinations for preservice and inservice inspection of the inaccessible DP-SC components, including concrete infill, of the integrated RB. (SE Section 5.18, LTR Section 5.18)

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8.14 While the proposed approach and considerations in LTR Section 6.22 for establishing a preservice and inservice inspection program is generally reasonable, an applicant referencing the LTR in a future application shall submit for NRC staff review a plant-specific program that includes specific considerations and NDE methods that will be implemented for inaccessible DP-SC components or areas, including concrete infill, of the SCCV. (LTR Section 6.22; SE Section 6.22)

8.15 The modeling description and acceptance criteria for the SCCV integrity analyses for combustible gas control in LTR Section 6.23.2 shall be supplemented as follows. For the required pressure and dead load, the SCCV acceptance criteria shall demonstrate that the SCCV inner faceplate strains satisfy Factor Load Category requirements for liner strain allowable limits presented in ASME Code, Section III, Division 2, Subarticle CC-3720, Table CC-3720-1 for each of “membrane” and “combined membrane and bending,” i.e., both of which must be met for compression and/or tension strain applicable to the loading condition. Further, the ASME Code-specified material properties corresponding to metal temperature(s) resulting from the hydrogen generated event shall be used in the finite element model of the SCCV used for the analyses. (LTR Section 6.23.2; SE Section 6.23.2)

9.0 CONCLUSIONS

Based on the above discussion, the NRC staff concludes that the proposed design-specific methodology/approach for materials, design, fabrication, construction, testing and examination of the BWRX-300 SCCV and RB using DP-SC modules, as described in the LTR, are reasonable and adequate as an acceptable way of meeting applicable regulations identified in SE Section 2.0, subject to the limitations and conditions as provided in Section 8.0. As previously discussed in Section 1 of the SE, the NRC staff will evaluate the regulatory compliance of the final design of the BWRX-300 Integrated RB DP-SC structures and components, including the SCCV, during future licensing activities when an application is submitted in accordance with 10 CFR Part 50 or 10 CFR Part 52, as applicable.

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