USNRC–CNSC Memorandum of Cooperation

JOINT REPORT
Concerning
X Energy's Reactor Pressure Vessel Construction Code Assessment White Paper

June, 2021

U.S. NRC–CNSC Memorandum of Cooperation: Joint Report
X Energy's Reactor Pressure Vessel Construction Code Assessment White Paper

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Preface

On August 15, 2019, the Canadian Nuclear Safety Commission (CNSC) and the U.S. Nuclear Regulatory Commission (USNRC) signed a joint memorandum of cooperation (MOC) (Ref. 1) aimed at enhancing technical reviews of advanced reactor and small modular reactor technologies. This MOC is intended to supplement and strengthen the existing memorandum of understanding between the two parties signed in August 2017 (Ref. 2). Additional information on international agreements and the CNSC can be found at https://nuclearsafety.gc.ca/eng/resources/international-cooperation/international-agreements.cfm.

Cooperation between the CNSC and the USNRC provides opportunities for both agencies to share scientific information about technical matters that could support more efficient reviews of small modular reactor and advanced reactor technologies. Cooperative activities can be conducted, while acknowledging differences between the Canadian and U.S. regulatory frameworks and licensing processes, by leveraging fundamental scientific and engineering findings from other reviews to the extent practicable.

Activities under the MOC are coordinated by a subcommittee of the CNSC-USNRC Steering Committee, called the Advanced Reactor Technologies and Small Modular Reactors (ART-SMR) Subcommittee. The subcommittee approves and prioritizes work plans to accomplish specific cooperative activities under the MOC.

Cooperative activities between both organizations are established and governed under Terms of Reference (see https://nuclearsafety.gc.ca/eng/resources/international-cooperation/international-agreements/cnsc-usnrc-smr-advanced-reactor-moc-tor.cfm) and are designed to do the following:

- Contribute to better use of the regulators' resources by leveraging the technical knowledge and capabilities between the USNRC and the CNSC.
- Enhance the depth and breadth of the respective CNSC and USNRC staffs' understanding of the counterpart nation's regulatory review activities and requirements.
- Enhance the joint opportunities for learning about and understanding the advanced reactor and small modular reactor technologies being reviewed.

The decision of the CNSC and the USNRC to cooperate in activities that concern specific reactors and their associated vendors depends on the state of the design. It is based on the following factors that the vendor or applicant must address in a proposed work plan that both regulators accept:

- The extent the vendor or applicant is engaging in meaningful licensing or prelicensing activity with each regulator.

- The similarities between the vendor's engagement activities in each country in order to achieve a useful cooperation outcome. For example, the objectives of the CNSC's vendor design review process differ from those of the U.S. certification and engagement processes, yet opportunities exist for leveraging information between the two regulators.

- The timelines for engaging with each regulator

- The way the vendor is sharing information about its design with both regulators to enable cooperation.

These joint products are envisioned to enhance advanced reactor design reviews and support regulatory reviews by each regulator, as appropriate.

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Executive Summary

This report documents the results of collaborative activities between the Canadian Nuclear Safety Commission (CNSC) and the U.S. Nuclear Regulatory Commission (USNRC) concerning a request by X Energy, LLC (X-Energy or the vendor), to obtain feedback on its position about the Xe-100 reactor pressure vessel (RPV) construction code assessment. The results of this report may be used by the vendor or a potential licensee in future discussions with either regulator, but they are not legally binding on the CNSC or the USNRC.

In a letter dated July 13, 2020 (USNRC Agencywide Documents Access and Management System Accession No. ML20202A598), X-Energy submitted to the USNRC a white paper titled "Reactor Pressure Vessel Construction Code Assessment," Revision 1 (Ref. 3), for review. X-Energy also requested informal feedback on the approach it has taken with regard to code identification, assessment, and selection and the adequacy of the regulatory analysis and conclusions made in the code selection for the RPV. This white paper may be developed into a licensing topical report or technical report for reference by future Xe-100 license applicants.

In July 2020, X-Energy began a Phase 2+ vendor design review (VDR) with the CNSC. A VDR is an optional service that the CNSC provides to assess a vendor's reactor design. The primary purpose of a VDR is to offer feedback to the vendor about how it is addressing Canadian regulatory requirements and the CNSC's expectations in its design and design activities. As part of X-Energy's submission for focus area 11, Pressure Boundary Design, pursuant to the VDR, X-Energy submitted the same RPV construction code assessment white paper that it submitted to the USNRC.

In its white paper, X-Energy has proposed to design and analyze the RPV to the requirements in American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code, Section III, "Rules for Construction of Nuclear Facility Components," Division 5, "High Temperature Reactors" (Ref. 4). However, X-Energy has proposed to fabricate the vessel to the quality assurance and general requirements for construction found in ASME B&PV Code, Section VIII, "Rules for Construction of Pressure Vessels," Division 2, "Alternative Rules" (Ref. 5), and to stamp the vessel to ASME B&PV Code, Section VIII, Division 2.

The CNSC and the USNRC have reviewed the white paper and concluded that X-Energy's proposed approach for the design and fabrication of the Xe-100 RPV is viable, provided X-Energy includes the additional technical justification requested in this report and addresses both regulators' observations documented in this report. The proposed approach could be used to establish criteria for the Xe-100 design and fabrication of the RPV.

Key observations that inform the above conclusion include the following:

- A fundamental consideration is that that the design, construction, inspection, and testing of the RPV shall be such that the Xe-100 design meets all relevant general safety objectives and goals, including dose acceptance criteria, adequacy of plant defense in depth, and fulfilment of all fundamental safety functions, during operation and accidents for the expected lifetime of the reactor.

- The safety functions fulfilled by the RPV are fundamental elements of its safety classification and support the selection of appropriate designs and manufacturing codes, such that RPV will be designed, fabricated, erected, and tested to quality standards commensurate with the safety functions it performs.

- X-Energy bases its approach on the claim that RPV-required safety functions are exclusively geometry related and that the pressure-retention function of the RPV is not required for safety. All claims must be substantiated and supported by credible and quality-assured evidence. As such, the deterministic and probabilistic safety analyses for the reactor design must support the decisions for selected codes, safety functions, and classifications over the life of the reactor. All relevant design and operation considerations (e.g., the prevention of brittle fracture and rapid propagation of fractures, the adverse impacts on safety of air or water ingress, radiation embrittlement, allowable stresses, inspection and testing) will need to be adequately addressed.

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List of Acronyms

ADAMS	Agencywide Documents Access and Management System
ARDC	advanced reactor design criterion/criteria
ART-SMR	Advanced Reactor Technologies and Small Modular Reactors (Subcommittee)
ASME	American Society of Mechanical Engineers
B&PV	boiler and pressure vessel
CFR	*Code of Federal Regulations*
CNSC	Canadian Nuclear Safety Commission
DBA	design-basis accident
DC	design criterion/criteria
DEC	design extension condition
HTGR	high-temperature gas-cooled reactor
LWR	light-water reactor
MOC	memorandum of cooperation
NEI	Nuclear Energy Institute
PDC	principal design criterion/criteria
PIE	postulated initiating event
REGDOC	regulatory document
RG	regulatory guide
RISC	risk-informed safety class
RPV	reactor pressure vessel
SSC	structure, system, and component
TRISO	tristructural isotropic
USNRC	U.S. Nuclear Regulatory Commission
VDR	vendor design review
X-Energy	X-Energy, LLC

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1. Introduction

This section documents the history of the decision by the U.S. Nuclear Regulatory Commission (USNRC) and the Canadian Nuclear Safety Commission (CNSC) to establish this cooperative activity.

1.1. X-Energy Engagement with the USNRC

In a letter dated July 13, 2020 (USNRC Agencywide Documents Access and Management System (ADAMS) Accession No. ML20202A598) (Ref. 3), X-Energy, LLC (X-Energy or the vendor), submitted to the USNRC a white paper titled "Reactor Pressure Vessel Construction Code Assessment," Revision 1. This white paper provides a regulatory analysis of possible construction codes from the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code for use in the design, procurement, fabrication, and construction activities associated with the Xe-100 reactor design. X-Energy provided the white paper to the USNRC for its review and informal feedback about X-Energy's plans with regard to code identification, assessment, and selection and about the adequacy of the regulatory analysis and conclusions made in its code selection. This white paper may be developed into a licensing topical report or technical report for reference by future Xe-100 license applicants.

1.2. X-Energy Engagement with the CNSC

In July 2020, X-Energy began a combined Phase 1 and 2 vendor design review (VDR) with the CNSC. A VDR is an optional service that the CNSC provides to assess a vendor's reactor design. The primary purpose of a VDR is to offer feedback to the vendor about how it is addressing Canadian regulatory requirements and CNSC expectations in its design and design activities. As part of X-Energy's submission for VDR focus area 11, Pressure Boundary Design, X-Energy submitted the same white paper that it submitted to the USNRC.

1.3. Basis for Cooperative Activity on Xe-100

Because regulators in both Canada and the United States are reviewing the X-Energy white paper, which presents a specific case from a design under development, the CNSC, the USNRC, and X-Energy staff agreed that a collaborative CNSC–USNRC review of X-Energy's proposed approach to design and fabrication codes for the reactor pressure vessel (RPV) serves as an appropriate opportunity for cooperation. The scope of this report is limited to the ASME B&PV Code selections for the Xe-100 RPV.

2. Scope and Objectives for the Cooperative Activity

The main objective of this report is to document the USNRC and the CNSC staff's joint preliminary assessment of X-Energy's RPV code assessment white paper. In its white paper, X-Energy evaluates the regulatory and technical aspects of choosing a construction code for the Xe-100 RPV commensurate with the importance of the safety functions that will be credited in the application. The construction code selected for the Xe-100 RPV must address both safety functions X-Energy plans to credit in the application, namely, (1) the licensing basis function of maintaining component geometries across all licensing basis events and (2) the operational function of pressure retention of the helium heat transport fluid.

X-Energy plans to perform the design analyses of the Xe-100 RPV in accordance with the rules in ASME B&PV Code, Section III, "Rules for Construction of Nuclear Facility Components," Division 5, "High Temperature Reactors," Class A, for all design conditions and service loading. X-Energy plans to construct and stamp the RPV in accordance with ASME B&PV Code, Section VIII, "Rules for Construction of Pressure Vessels," Division 2, "Alternative Rules," for pressure and deadweight design only, with quality assurance requirements consistent with Section VIII construction.

With the proposed approach, X-Energy expects that the RPV physical design and design life bound the requirements from the two code sections.

To the extent practicable, and within the prelicensing processes between X-Energy and the regulators, the CNSC and the USNRC have each assessed how the code selection approach addresses regulatory requirements in each country and have shared experiences and identified issues with each other.

3. Regulatory Criteria, Observations, and Ongoing Engagement

3.1. CNSC

3.1.1. CNSC Disclaimer

Nothing in this report fetters the powers, duties, or discretion of CNSC-designated officers, CNSC inspectors, or the Commission respecting regulatory decisions or taking regulatory action. Nothing in this report is to be construed or interpreted as affecting the jurisdiction and discretion of the Commission in any assessment of any application for licensing purposes under the *Nuclear Safety and Control Act* (Ref. 6), its associated regulations, or the *CNSC Rules of Procedure*. This report does not involve the issuance of a licence under section 24 of the *Nuclear Safety and Control Act*. The conclusions in this report are those of the CNSC staff.

3.1.2. Regulatory Framework

The CNSC generally adopts a risk-informed, performance-based regulatory approach; therefore, it does not prescribe specific codes and standards for the design and manufacturing of systems, structures, and components (SSCs). However, it requires that the quality of SSCs be commensurate with their safety classification for design, construction, and maintenance.

3.1.2.1 Safety Classification

Section 7.1, "Safety classification of structures, systems and components," of regulatory document REGDOC-2.5.2, "Design of Reactor Facilities: Nuclear Power Plants," issued May 2014 (Ref. 7), states that "[t]he design authority shall classify SSCs using a consistent and clearly defined classification method. The SSCs shall then be designed, constructed, and maintained such that their quality and reliability is commensurate with this classification." The following are the main considerations to assess the importance to safety of SSCs:

- the safety function(s) performed
- the consequences of failures
- the probability that the SSCs will be called upon to perform the safety function
- the time following a postulated initiating event (PIE) at which the SSC is required to operate, as well as the expected duration of operation

Therefore, the RPV''s safety classification shall be the result of a systematic, consistent, and well-defined process. X-Energy maintains that the required safety functions for the RPV are geometry related to ensure the following:

- The decay heat removal flowpath is not disrupted.
- Control rods can shut down and maintain shutdown of the core.

The approach to RPV design proposed for the Xe-100 is maintaining the geometry of the system and ensuring the leak-tight integrity of the reactor helium pressure boundary without an explicit requirement to perform a radiological safety function. The radiological safety functions under all relevant operating and accident conditions are dependent on the demonstrated features inherent in tristructural isotropic (TRISO) fuel retaining fission products.

However, X-Energy acknowledges that the RPV contains high-energy gas under high pressure, and disruptive rupture of the pressure vessel is not acceptable. RPV safety classification and subsequent design and manufacturing code selection should be such that all nuclear (i.e., geometry retention) and conventional (i.e., preclusion of the disruptive rupture of the RPV) safety functions are met with high confidence. The manufacturing of the RPV according to conventional/industrial standards, rather than ASME nuclear standards and manufacturing requirements, requires careful consideration to ensure the following:

- All relevant aspects are addressed.
- All required safety functions are fulfilled.
- Adequate safety margins are incorporated.

Relevant considerations on the exclusion of massive pressure vessel failures for deterministic safety analysis can be found under Section 4.2.3.3, "Guidance for beyond-design-basis accidents," of REGDOC-2.4.1, "Deterministic Safety Analysis" issued May 2014 (Ref. 8):

> "Some massive failures of pressure vessels can be exempted from the deterministic safety analysis, if it can be demonstrated that these failures are sufficiently unlikely, and if all the following conditions are satisfied:
>
> - the vessel is designed, fabricated, installed, and operated in compliance with the nuclear requirements of the applicable engineering codes and other requirements
> - an in-service inspection program is implemented
> - operating experience, with vessels of similar design and operating condition, support a low likelihood of failure
> - the vessel has adequate restraints to limit propagation of damage to the plant"

The guidance of Section 7.1 of REGDOC-2.5.2 conveys the expectation that, when an SSC contributes to the performance of several safety functions of different categories, the SSC should be assigned to the class corresponding to the highest category of those safety functions. Deciding which ASME code sections are applicable to the Xe-100 RPV would require sufficiently developed deterministic and probabilistic safety analyses in order to determine the range of consequences for the complete set of PIE considered for the Xe-100. This has yet to be demonstrated.

The challenge in this context is to achieve the proper balance between maintaining an adequate level of safety and not imposing unnecessary conservatism and constraints on the vendor/designer.

3.1.2.2 Design Rules and Limits

Section 7.5, "Design rules and limits," of REGDOC-2.5.2 requires that engineering design rules be derived for all SSCs. These rules shall comply with appropriate accepted engineering practices. The guidance in Section 7.5 recommends the following:

> Methods to ensure a robust design are applied, and proven engineering practices are adhered to in the design, as a way to ensure that the fundamental safety functions would be achieved in all operational states, DBAs [design-basis accidents] and DECs [design extension conditions].

In the proposed approach, the RPV design and analyses are consistent with the rules in ASME B&PV Code, Section III, Division 5, Class A, for all design conditions and service loading, and the RPV will be constructed to ASME B&PV Code, Section VIII, Division 2. The quality assurance and general requirements will be in accordance with construction under ASME B&PV Code, Section VIII. This novel approach (i.e. design and construction being done according to different ASME Code sections, construction of RPV being done with commercial vessel code), will require a detailed and careful analysis to demonstrate that all relevant design, construction, and operational aspects have been adequately considered.

3.1.2.3 Pressure-Retaining Structures, Systems, and Components

X-Energy states that the pressure-retention capability of the RPV is not classified as important to safety. From the RPV design approach, the important-to-safety functions of the RPV are only to ensure the geometry of the system is maintained. Even if the RPV's pressure-retention capability is ultimately not classified as important to safety, the CNSC staff expects X-Energy to demonstrate that the proposed fabrication method can achieve the required safety-related function of maintaining the RPV geometry.

Section 7.7, "Pressure-retaining structures, systems and components," of REGDOC-2.5.2 deals with pressure-retaining SSCs. It states that "[a]ll pressure-retaining SSCs shall be protected against overpressure conditions, and shall be classified, designed, fabricated, erected, inspected, and tested in accordance with established standards. For DECs, relief capacity shall be sufficient to provide reasonable confidence that pressure boundaries credited in severe accident management will not fail." It also requires the minimization of the likelihood of flaws in pressure boundaries and the timely detection of flaws in pressure boundaries important to safety.

In addition, Section 7.7 of REGDOC-2.5.2 requires that pressure-retaining components whose failure will affect nuclear safety be designed to permit inspection of their pressure boundaries through the design life. However, the white paper does not clearly address inspection requirements and the differences between the code sections.

It should be noted that the safety assessment of the consequences of the failure of pressure-retaining SSCs may be limited not only to the effects on fuel cooling but also to the effects on SSCs important to safety (e.g., pipe whip, high-pressure and -temperature gas discharge, impact of a helium environment on digital electronic equipment). An additional concern in case of pressure boundary failure is the ingress of air or steam and their chemical effects on fuel and core structures.

Further, as stated in Section 7.7 of REGDOC-2.5.2, an important aspect is the interconnection of systems operating at different pressures. Failure of the interconnection shall be considered. Both systems shall either be designed to withstand the higher pressure or provisions shall be made so that the design pressure of the system operating at the lower pressure will not be exceeded. Given the configuration of the X-Energy design, the design of the RPV and the reactor helium pressure boundary components shall include this aspect. However, the X-Energy white paper does not include additional details on this issue.

The guidance in Section 7.7 of REGDOC-2.5.2 states that, for the design of pressure-retaining SSCs, the selection of codes and standards should be commensurate with the safety class. In this respect, REGDOC-2.5.2 mentions acceptable industry standards, such as the ASME B&PV Code and CSA Group N285, "General Requirements for Pressure-Retaining Systems and Components in CANDU Nuclear Power Plants" (Ref. 9). However, REGDOC-2.5.2 does not mention any specific division or section of the codes. Alternative codes and standards may be used, but the proponent should provide adequate justification that this would result in an equivalent or superior level of safety. The guidance in Section 7.7 of REGDOC-2.5.2 sets an expectation that "[t]he design should make provisions to limit stresses and deformation of SSCs important to safety during and after PIEs." The list of PIEs should be comprehensive, and the design analysis should include the loads generated by them and the stress analysis.

The CNSC staff expects that the design will minimize the likelihood of flaws in pressure boundaries. As a result, the RPV should be designed with sufficient margin to ensure that, under all operating configurations, the material selected has sufficient fracture toughness to minimize the probability of rapidly propagating fractures.

3.1.2.4 Defense-in-Depth Considerations

The design and fabrication of the RPV needs to consider its role in defense in depth for the Xe-100. As a general rule, the CNSC staff expects that the design would include conservatism and high-quality construction to provide confidence that failures and deviations from normal operations are minimized and accidents are prevented. Therefore, the demonstration that RPV pressure-retention capability is not needed for safety should be complemented by the design measures taken to minimize the frequency of such occurrences.

3.1.3. Previous Prelicensing Engagement with the Vendor

The VDR with X-Energy is ongoing and is scheduled to be completed by the middle of 2023.

The CNSC staff's analysis of the ASME B&PV Code selections for the X-Energy RPV will continue to evolve as further details on the X-Energy design are received and analyzed as part of the Phase 2+ VDR.

3.2. USNRC

3.2.1. Regulatory Framework

The USNRC has no regulatory requirements that specify the engineering codes or standards that must be used for the vessels in advanced reactors. Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic licensing of production and utilization facilities," Appendix A, "General Design Criteria for Nuclear Power Plants" (Ref. 10), establishes minimum requirements for the principal design criteria (PDC) for light-water reactors (LWRs) and provides guidance for establishing PDC for other types of nuclear power units. Regulations in 10 CFR Part 52, "Licenses, certifications, and approvals for nuclear power plants" (Ref. 11), also establish the general design criteria of Appendix A to 10 CFR Part 50 as the minimum requirements for the PDC for LWRs and as guidance for establishing PDC for other types of nuclear power units. Regulatory Guide (RG) 1.232, "Guidance for Developing Principal Design Criteria for Non-Light-Water Reactors" (Ref. 12), provides guidance that may be used by non-LWR reactor designers, applicants, and licensees to develop PDC for any non-LWR designs. Applicants may use this RG to develop all or part of the PDC. They are free to choose among the various design criteria to develop each PDC, after considering the underlying safety basis for the criterion and evaluating the rationale for the adaptation described in RG 1.232.

The staff may approve the use of generally recognized codes and standards, as supplemented or modified, if all of the following are true:

- A reactor vessel is designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to be performed.
- The USNRC staff determines that the generally recognized codes and standards are applicable, adequate, and sufficient.
- The codes and standards are supplemented or modified, as necessary, to assure a quality product in keeping with the required safety function.

Furthermore, 10 CFR 50.69, "Risk-informed categorization and treatment of structures, systems and components for nuclear power reactors," provides an applicant for an NRC license under 10 CFR Part 50 and 10 CFR Part 52 with an alternative to compliance with certain requirements, including those in 10 CFR Part 21, "Reporting of defects and noncompliance" (Ref. 13), and Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants," to 10 CFR Part 50. An applicant's choice to comply with 10 CFR 50.69 in lieu of the regulations listed in that section would require the classification of the RPV and helium pressure boundary system as Risk-Informed Safety Class (RISC)-3 or RISC-4 SSCs. If these systems can be classified as RISC-3 or RISC-4 and the applicant complies with 10 CFR 50.69, the applicant would not need to meet the requirements of 10 CFR Part 21 or Appendix B to 10 CFR Part 50. Also, RG 1.233, "Guidance for a Technology-Inclusive, Risk-Informed, and Performance-Based Methodology to Inform the Licensing Basis and Content of Applications for Licenses, Certifications, and Approvals for Non-Light-Water Reactors" (Ref. 14), endorses Nuclear Energy Institute (NEI) 18-04, "Risk-Informed Performance-Based Technology Inclusive Guidance for Non-Light Water Reactor Licensing Basis Development," issued August 2019 (Ref. 15), which provides a method for the classification and special treatment of SSCs that are fundamental to the safe design of non-LWRs. This approach is commonly referred to as the licensing modernization project. While NEI 18-04 does not correspond to actual regulatory acceptance criteria, it is a vehicle to determine risk significance, support SSC classification, determine special treatment requirements, and identify appropriate programmatic controls that could be used to assess a proposal similar to that suggested by X-Energy in the white paper.

3.2.1.1 Modular High-Temperature Gas-Cooled Reactor Design Criteria

Since the Xe-100 vessel is part of the reactor coolant boundary, the PDC related to the reactor coolant system boundary may also be applicable. From RG 1.232, Appendix C, modular high-temperature gas-cooled reactor (HTGR) Design Criteria (DC) 14, 15, 30, 31, and 32 may have some applicability to the design of the reactor vessel. In consideration of all these DC, the most important aspect, considering the pressure boundary function, is that a core geometry change should not be permitted since it could affect the ability of the core to be cooled.

Modular HTGR DC 14 provides that the reactor helium pressure boundary is designed, fabricated, erected, and tested to have an extremely low probability of the following:

- abnormal leakage
- rapidly propagating failure
- gross rupture
- unacceptable ingress of moisture, air, secondary coolant, or other fluids

This is an important consideration in the design of the reactor vessel. Gross rupture to the extent of disrupting the ability to cool the core when no helium is available will need to be prevented.

Modular HTGR DC 15 is important to ensure that the design of the reactor vessel has enough margin to ensure the DC are not exceeded during any condition of normal operation, including anticipated operational occurrences.

Modular HTGR DC 30 provides that the reactor coolant boundary is designed, fabricated, erected, and tested to the highest quality standards practical. The ability to detect and, to the extent practical, identify the location of the source of reactor helium leakage should be provided. In addition, the ability to detect the ingress of moisture, air, secondary coolant, or other fluids within the reactor helium pressure boundary should be provided. To the extent HTGR DC 30 applies "the highest quality standards practical," it could be more stringent than Advanced Reactor Design Criterion (ARDC) 1 from RG 1.232, Appendix A, which states that SSCs important to safety shall be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to be performed. HTGR DC 30 could therefore be seen to conflict with ARDC 1. The safety functions of the reactor coolant boundary are to maintain core geometry and prevent the ingress of moisture, air, secondary coolant, and other fluids that could have a detrimental impact on the fuel or the core structures that support the fuel. However, the reactor coolant boundary does not perform a safety function with respect to helium leakage. Accordingly, the design, fabrication, erection, and testing of the reactor coolant boundary to the highest quality standards need not address helium leakage and may be beyond those commensurate with its safety functions.

Modular HTGR DC 31 provides that the reactor coolant system, including the reactor vessel, does not behave in a brittle manner, and the probability of a rapidly propagating fracture is minimized. If a reactor vessel behaves in a brittle manner, the probability of a gross rupture of the vessel occurring will be much higher. Modular HTGR DC 32 provides for a material surveillance program. This will ensure that material parameters are acceptable over time as materials age thermally and from neutron irradiation. The proper selection of the design parameters, design standards, and an ongoing material surveillance program is essential to the prevention of a brittle failure.

3.2.1.2 Observations

The Xe-100 reactor has the following characteristics:

- The design is a pebble-bed HTGR.

- It is a 200-megawatt thermal (80-megawatt electric) reactor, built as a standard "four-pack" plant generating about 300 megawatts electric.

- The reactor transports core heat using helium to the steam generator for conversion into high-quality steam.
- Each Xe-100 has the following:
  - RPV
  - steam generator vessel
  - double-walled cross-vessel
  - core support barrel
  - graphite block
  - fuel pebbles

X-Energy states in its white paper that the Xe-100 reactor design can meet all anticipated specified acceptable radionuclide release criteria during the most challenging event sequence, which is a depressurized forced loss of cooling with no credit taken for the helium inventory. The classification of the RPV is safety related but only to ensure the geometry of the system is maintained. The white paper identifies that the helium coolant is not relied upon for heat transfer during a loss-of-coolant event because of the use of TRISO-coated fuel particles and the pebble itself. It states that the fuel is able to withstand very high temperatures and is not damaged as a result of a loss of cooling.

Any future submittal should address the following USNRC staff observations on the white paper:

- As part of any application, X-Energy should provide justification that the RPV will not serve a safety-related pressure boundary function. This may include the need for helium coolant activity limits, along with demonstrating that the fission product retention within the TRISO fuel and the operating limits are within the limits for the TRISO fuel. This will also include demonstrating that during a loss of the helium coolant, the RPV will still operate within the design conditions for the RPV. In addition, the vendor will need to demonstrate that the vessel is flaw tolerant such that rapidly propagating failure and gross rupture have a very low probability of occurrence.

- As a safety-related item, unless the vendor, an applicant, or a licensee voluntarily complies with the requirements of 10 CFR 50.69 for the RPV, such entity will have to meet the requirements of Appendix B to 10 CFR Part 50, consistent with existing regulatory requirements. X-Energy should explain how the commercial quality assurance measures from ASME B&PV Code, Section VIII, Division 2, provide an acceptable alternative for this component. This explanation will need to be more detailed than the evaluation provided in Table 3, "General Quality Requirement Comparison," of the white paper. X-Energy should also describe any supplements or modifications to the quality assurance measures in ASME B&PV Code, Section VIII, Division 2, and indicate whether the application will include an exemption request from Appendix B to 10 CFR Part 50.

- In Table 3 of the white paper, X-Energy states, in part, that "Adopting Section VIII, Division 2 would also not prevent implementation of 10 CFR Part 21 reporting requirements." X-Energy should explain how 10 CFR Part 21 requirements will be implemented during the RPV manufacturing and operating phases.

- The USNRC staff has not identified any issue with X-Energy's proposed use of the rules in ASME B&PV Code, Section III, Division 5, Class A, for all design conditions and service loading. The USNRC staff is currently reviewing Division 5 for endorsement. In designing the vessel, X-Energy should consider any conditions or limitations identified in any RG in which the NRC ultimately endorses Division 5.

- Section 4.2.3 of the white paper states that ASME B&PV Code, Section III, Division 5, requires more recordkeeping for welding than ASME B&PV Code, Section VIII, Division 2, but that the differences are minor and largely administrative. X-Energy should consider the benefits of maintaining these more detailed records, namely that they (1) may aid in the identification of potential increased residual stress in the finished weld, which may lead to the need for increased inservice inspection frequency, (2) may also aid with root cause investigation if a flaw is detected, (3) support assessing the susceptibility to cracking based on fabrication records, and (4) support determining the appropriate examinations and frequency under a program such as the reliability integrity management program under ASME B&PV Code, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," Division 2, "Requirements for Reliability and Integrity Management (RIM) Programs for Nuclear Power Plants." (Ref. 16).

- Section 4.2.4 of the white paper compared the nondestructive examinations specified by ASME B&PV Code, Section III, Division 5, Class A, and ASME B&PV Code, Section VIII, Division 2. It states that the weld inspections are more extensive in ASME B&PV Code, Section III, and it did not conclude that the provisions in ASME B&PV Code, Section VIII, are sufficient for the RPV to meet its safety function. X-Energy should evaluate whether the provisions of ASME B&PV Code, Section VIII, are sufficient to ensure the RPV will be capable of performing its safety functions and identify any areas where ASME B&PV Code, Section VIII, will need to be supplemented. Because the safety-related function of the RPV is similar to the function of core support in ASME B&PV Code, Section III, Division 1, "Metallic Components" (Ref. 17), Class NG, or ASME B&PV Code, Section III, Division 5, Class SM, a comparison between these codes may provide beneficial insights to this evaluation.

- Section 3.3.2 of the white paper acknowledges that relevant PDC require an ongoing inservice inspection program for the reactor helium pressure boundary, but the paper did not discuss this program. X-Energy should include a description of the inservice inspection program.

- X-Energy should discuss limiting flaw sizes for a component that provides only core support and geometric constraint to aid in the demonstration of acceptable levels of quality and safety.

- If the pressure vessel does not have a safety-related function for pressure boundary integrity, X-Energy should consider and assess the potential for the in-leakage of contaminants and the associated impacts on the fuel, the graphite, and the vessel.

3.2.2. Previous Prelicensing Engagement with the Vendor

The USNRC and X-Energy began preapplication interactions in September 2018. During these interactions, the parties have discussed the Xe-100 design approach and its schedule. Since then, the USNRC staff has continuously engaged with X-Energy on preapplication activities. As part of these preapplication activities, X-Energy has submitted the "X Energy, LLC Topical Report Quality Assurance Program Description," Revision 3, dated August 7, 2020 (Ref. 18), for the design certification of the Xe-100 reactor. The USNRC approved the topical report on September 4, 2020 (Ref. 19).

X-Energy also submitted the "XSTERM Code Suite Mechanistic Source Term Verification and Validation Plan White Paper," dated October 7, 2019 (Ref. 20), requesting informal feedback. The USNRC staff provided its observations in a letter dated March 10, 2020 (ADAMS Accession No. ML20069E077). X-Energy plans to submit other topical reports and white papers as part of its preapplication activities.

4. Results of Joint CNSC–USNRC Discussions

4.1. CNSC–USNRC Joint Conclusion

Both the CNSC and USNRC have reviewed the white paper provided by X-Energy. The main objective of the document is to provide the basis for X-Energy's intent to design the reactor and heat transport system to meet ASME B&PV Code, Section III, Division 5, and to manufacture these components in accordance with ASME B&PV Code, Section VIII, Division 2.

Both regulators have the following mutual observations that any future licensing application should address:

- The application would need to demonstrate the RPV importance to safety only for maintaining the core geometry and not for pressure boundary. Such demonstration includes substantiation of required safety functions for the Xe-100 through deterministic and probabilistic safety analysis, as well as a robust safety classification that supports the selection of design and construction code the Xe-100.

- Inservice inspections need to be further considered. The construction requirements may differ from preservice inspection requirements (e.g., volumetric versus visual) and can affect the implementation of the inservice inspection program. The application should describe how this program will be affected.

- The application should address limiting the flaw sizes in the RPV to ensure the expected level of quality and safety.
- The application needs to provide information about the ingress of air or steam as possible contaminants and discuss the implications. It should also address the potential for the in-leakage of contaminants and the associated impacts on the fuel, the graphite, and the vessel.

Based on the white paper, the USNRC and the CNSC staff have concluded that X-Energy's proposed approach for the design and fabrication of the Xe-100 RPV is viable, provided X-Energy includes additional technical justification and addresses the regulators' observations both as stated above and as given in Section 3.

4.2. Basis for CNSC–NRC Joint Conclusion

The following key regulatory considerations and the main aspects identified in the white paper provide the basis for the conclusions reached in Section 4.1:

- The RPV must be designed, fabricated, erected, and tested to quality standards commensurate with the safety functions it performs. The safety functions are fundamental elements of the RPV's safety classification.
- The codes and standards proposed for use may be chosen and subsequently supplemented or modified as necessary to assure a quality product, provided that the level of safety is justified.
- The RPV must perform the safety function of maintaining core geometry, which ensures the following:
    - The decay heat removal flowpath is not disrupted
    - Control rods can shut down the core and maintain the core in a stable shutdown state.
- The maintenance of the core geometry aids in the following aspects of the design, which also need to be satisfied:
    - The overall reactor design can meet acceptable radionuclide release criteria during the most challenging event sequences.
    - Normal operation release limits can be met.
    - Anticipated operational occurrences and design-basis accidents do not result in exceeding established dose acceptance criteria.

  - Quantitative and qualitative safety goals should be met.

- The deterministic and probabilistic safety analyses for the reactor design must support the decisions for the selected codes, safety functions, and classifications over the life of the reactor.

- Identified safety functions must be achieved in all operational states.

- The RPV design should include detail sufficient to demonstrate that all relevant design, manufacturing, and operational aspects have been adequately considered.

- The helium pressure boundary needs to be designed, manufactured, tested, and inspected to prevent brittle fracture and the rapid propagation of fractures.

- Air or water ingress into the RPV during pressure boundary failures that could lead to adverse chemical reactions needs to be considered.

5. References

1. "Memorandum of Cooperation on Advanced Reactor and Small Modular Reactor Technologies between the United States Nuclear Regulatory Commission and the Canadian Nuclear Safety Commission," August 15, 2019 (ADAMS Accession No. ML19275D578)

2. "Memorandum of Understanding between the United States Nuclear Regulatory Commission and the Canadian Nuclear Safety Commission for the Exchange of Technical Information and Cooperation in Nuclear Safety Matters," August 2017 (ADAMS Accession No. ML196168A017)

3. X-Energy, LLC, "Reactor Pressure Vessel Construction Code Assessment," Revision 1, July 2020

4. ASME Boiler and Pressure Vessel Code, Section III, "Rules for Construction of Nuclear Facility Components," Division 5, "High Temperature Reactors"

5. ASME Boiler and Pressure Vessel Code, Section VIII, "Rules for Construction of Pressure Vessels," Division 2, "Alternative Rules"

6. CNSC, *Nuclear Safety and Control Act*, January 2017

7. CNSC, REGDOC-2.5.2, "Design of Reactor Facilities: Nuclear Power Plants," May 2014

8. CNSC, REGDOC-2.4.1, "Deterministic Safety Analysis," May 2014

9. CSA Group, N285.0/N285.6 Series, "General Requirements for Pressure-Retaining Systems and Components in CANDU Nuclear Power Plants/Material Standards for Reactor Components for CANDU Nuclear Power Plants," Toronto, Canada

10. 10 CFR Part 50, "Domestic licensing of production and utilization facilities"

11. 10 CFR Part 52, "Licenses, certifications, and approvals for nuclear power plants"

12. RG 1.232, "Guidance for Developing Principal Design Criteria for Non-Light-Water Reactors"

13. 10 CFR Part 21, "Reporting of defects and noncompliance"

14. RG 1.233, "Guidance for a Technology-Inclusive, Risk-Informed, and Performance-Based Methodology to Inform the Licensing Basis and Content of Applications for Licenses, Certifications, and Approvals for Non-Light-Water Reactors"

15. NEI 18-04, "Risk-Informed Performance-Based Technology-Inclusive Guidance for Non-Light Water Reactor Licensing Basis Development," August 2019

16. ASME Boiler and Pressure Vessel Code, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," Division 2, "Requirements for Reliability and Integrity Management (RIM) Programs for Nuclear Power Plants"

17. ASME B&PV Code, Section III, "Rules for Construction of Nuclear Facility Components," Division 1, "Metallic Components"

18. "X Energy, LLC Topical Report Quality Assurance Program Description," Revision 3, August 7, 2020 (ADAMS Accession No. ML20220A413)

19. "Final Safety Evaluation by the Office of Nuclear Reactor Regulation Regarding the X-Energy Topical Report XEQAPD, 'Quality Assurance Program Description,' Revision 3 for the Design Certification of the Xe-100 Nuclear Power Reactor," September 4, 2020 (ADAMS Accession No. ML20233A910)

20. "XSTERM Code Suite Mechanistic Source Term Verification and Validation Plan," October 7, 2019 (ADAMS Accession No. ML19280B392)