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

October 24, 2024

Mr. Stephen Vaughn
Licensing Manager, Xe-100
X Energy, LLC.
801 Thompson Avenue
Rockville, MD 20852

SUBJECT: U.S. NUCLEAR REGULATORY COMMISSION FINAL SAFETY EVALUATION REGARDING THE X ENERGY, LLC., XE-100 PRINCIPAL DESIGN CRITERIA TOPICAL REPORT, REVISION 3 (EPID L-2022-TOP-0010)

Dear Mr. Vaughn:

By letter dated February 16, 2024 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML24047A308), X Energy, LLC., (X-energy) submitted for the U.S. Nuclear Regulatory Commission (NRC) staff's review, Revision 3 of its Xe-100 Principal Design Criteria topical report (TR). This TR describes the development of the principal design criteria (PDC) for the X-energy Xe-100 pebble-bed, high-temperature gas-cooled reactor.

The NRC staff's final safety evaluation for X-energy's Xe-100 Principal Design Criteria TR is enclosed. The NRC staff concluded that X-energy has provided a sufficient set of PDCs that are appropriate for establishing requirements for the Xe-100 design and that Revision 3 of the subject TR is suitable for referencing in future licensing applications for the Xe-100 design, subject to the limitations documented in the safety evaluation. The NRC staff requests that X-energy submit an accepted version of the Xe-100 Principal Design Criteria TR within 3 months of receipt of this letter. The accepted version shall incorporate this letter and the enclosed safety evaluation.

If you have any questions, please contact Adrian Muñiz via email at Adrian.Muniz@nrc.gov.

Sincerely,

Signed by Segala, John on 10/24/24

John Segala, Chief
Advanced Reactor Licensing Branch 2
Division of Advanced Reactors and Non-Power Production and Utilization Facilities
Office of Nuclear Reactor Regulation

Project No.: 99902071

Enclosure:
As stated

cc: Distribution via X-Energy Xe-100 GovDelivery
jmaddocks@x-energy.com

SUBJECT: U.S. NUCLEAR REGULATORY COMMISSION FINAL SAFETY EVALUATION REGARDING THE X ENERGY, LLC., XE-100 PRINCIPAL DESIGN CRITERIA TOPICAL REPORT, REVISION 3 (EPID L-2022-TOP-0010) DATED: OCTOBER 24, 2024

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X ENERGY, LLC - SAFETY EVALUATION OF XE-100 PRINCIPAL DESIGN CRITERIA TOPICAL REPORT (EPID L-2022-TOP-0010)

SPONSOR AND SUBMITTAL INFORMATION

Sponsor: X Energy, LLC. (X-energy)

Sponsor Address: X Energy, LLC.
801 Thompson Ave
Rockville, MD 20852

Project No.: 99902071

Submittal Date: February 16, 2024 (Revision 3)

Submittals Agencywide Documents Access and Management System (ADAMS) Accession Nos.: ML24047A308 (Revision 3), ML23181A172 (Revision 2), ML22195A260 (Revision 1)

Supplement and RAI response letter Date and ADAMS Accession No:

- X Energy, LLC., (X-energy) Responses to "NRC Staff's Preliminary Questions on the NRC Assessment of the X Energy, LLC Xe-100 Principal Design Criteria Licensing Topical Report," dated December 30, 2022 (ML22364A293)

Brief Description of the Topical Report: This topical report (TR) describes the development of the principal design criteria (PDCs) for the X-energy Xe-100 pebble-bed, high-temperature gas-cooled reactor (HTGR). As described in the TR, the PDCs were developed using guidance from Regulatory Guide (RG) 1.232, "Guidance for Developing Principal Design Criteria for Advanced (Non-Light Water) Reactors" (ML17325A611), Nuclear Energy Institute (NEI) 21-07, Revision 1, "Technology Inclusive Guidance for Non-Light Water Reactors, Safety Analysis Report Content: For Applicants Using the NEI 18-04 Methodology" (ML22060A190), and Xe-100-specific safety functions and design requirements. X-energy submitted the TR for the U.S. Nuclear Regulatory Commission (NRC or Commission) staff's review and approval as it is expected to be referenced in future Xe-100 licensing applications.

For additional details regarding the submittal, please refer to the documents located under the ADAMS Accession Numbers identified above.

Enclosure

1.0 REGULATORY EVALUATION

Regulatory Basis: In accordance with Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities," and Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants," applicants for a construction permit (CP), operating license (OL), standard design certification (DC), combined license (COL), standard design approval (SDA), or manufacturing license (ML) must submit PDCs for the proposed facility.

Specifically, the following regulations pertain to the PDCs:

- As required by 10 CFR 50.34(a)(3)(i), applications for a CP must include PDCs for the facility. An OL would reference a CP, which would include PDCs.
- As required by 10 CFR 52.47(a)(3)(i), applications for a standard DC must include PDCs for the facility.
- As required by 10 CFR 52.79(a)(4)(i), applications for a COL must include PDCs for the facility.
- As required by 10 CFR 52.137(a)(3)(i), applications for an SDA must include PDCs for the facility.
- As required by 10 CFR 52.157(a), applications for an ML must include PDCs for the reactor to be manufactured.

The regulations at 10 CFR 50.34(a)(3)(i), 10 CFR 52.47(a)(3)(i), 10 CFR 52.79(a)(4)(i), 10 CFR 52.137(a)(3)(i), and 10 CFR 52.157(a), state that the General Design Criteria (GDCs) in 10 CFR Part 50, Appendix A, "General Design Criteria for Nuclear Power Plants," establish the minimum requirements for the PDCs for water-cooled nuclear power plants similar in design and location to plants for which CPs have previously been issued by the Commission and provides guidance to applicants in establishing PDCs for other types of nuclear power units. Since the Xe-100 is not a water-cooled nuclear power plant design, its PDCs are not required to align with the minimum requirements in the GDCs in 10 CFR Part 50, Appendix A. Recognizing that the GDCs in 10 CFR Part 50, Appendix A, may not be appropriate for non-light-water reactors (non-LWRs), the NRC issued RG 1.232, which serves as guidance to develop PDCs for non-LWR designs. The guidance in RG 1.232, provides a general set of advanced reactor design criteria (ARDCs) and also includes design criteria for two specific non-LWR design concepts: the Sodium-Cooled Fast Reactor (SFR) and the Modular High-Temperature Gas-Cooled Reactor (MHTGR), designated as SFR-DCs in Appendix B, "Sodium-Cooled Fast Reactor Design Criteria," and MHTGR-DCs in Appendix C, "Modular High-Temperature Gas-Cooled Reactor Design Criteria," of RG 1.232.

NEI 18-04, Revision 1, "Risk-Informed Performance-Based Technology Inclusive Guidance for Non-Light Water Reactor Licensing Basis Development" (ML19241A336 (package)), presents a technology-inclusive, risk-informed, and performance-based process for the selection of licensing basis events (LBEs), the classification of structures, systems, and components (SSCs) and associated special treatments, and the determination of defense-in-depth (DID) adequacy.

RG 1.233, Revision 0, "Guidance for 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" (ML20091L698), provides the NRC staff's guidance on using a technology-inclusive, risk-informed, and performance-based methodology to inform the licensing basis and content of applications for non-LWRs. It endorses NEI 18-04 with clarifications as one acceptable method for informing the licensing basis and determining the appropriate scope and level of detail for parts of applications for licenses, certifications, and approvals for non-LWRs. The approach in RG 1.233 and NEI 21-07 is often called the Licensing Modernization Project (LMP).

NEI 21-07, Revision 1, "Technology Inclusive Guidance for Non-Light Water Reactors, Safety Analysis Report Content: For Applicants Using the NEI 18-04 Methodology" (ML22060A190) describes the scope and level of detail in specific portions of the first eight chapters of the safety analysis report (SAR) that are associated with the LMP-based safety analysis. NEI 21-07 includes guidance on design criteria such as Required Functional Design Criteria (RFDCs) and Complementary Design Criteria (CDCs) corresponding to SSCs that are classified as Safety Related (SR) and Non-Safety-Related with Special Treatment (NSRST). Regarding PDCs, NEI 21-07 proposes PDCs that include both RFDCs and CDCs, designated as PDC-RFDCs and PDC-CDCs respectively, to capture all safety-significant SSCs under the NEI 18-04 methodology.

RG 1.253, Revision 0, "Guidance for a Technology-Inclusive Content-of-Application Methodology to Inform the Licensing Basis and Content of Applications for Licenses, Certifications, and Approvals for Non-Light-Water Reactors" (ML23269A222), endorses NEI 21-07 with additions and clarifications as one acceptable methodology for use in developing certain portions of the SAR for an application for a non-LWR that follows the LMP.

The PDCs are integral to the review of the facility design and should be considered in the development of the facility and the SSC design bases. PDCs aid in the NRC staff's evaluation of other regulations and allow the NRC staff to have reasonable assurance that the design will conform to the design bases with adequate margins for safety.

2.0 TECHNICAL EVALUATION

2.1 Introduction

X-energy requested the NRC staff's review and approval of the Xe-100 PDCs in the TR to be used in applications for limited work authorizations, CPs and OLs under 10 CFR Part 50; or applications for limited work authorizations, standard DCs, COLs, SDAs, and MLs under the applicable regulations in 10 CFR Part 52. X-energy stated that the PDCs described in this TR were developed using the guidance in RG 1.232, NEI 21-07, and Xe-100-specific probabilistic risk assessment (PRA) safety functions (PSFs) and design features.

The NRC staff's review of Revision 1 of the TR (ML22195A260), submitted on July 13, 2022, resulted in a set of preliminary questions to which X-energy responded in a letter dated December 30, 2022 (ML22364A293). The NRC staff also conducted a regulatory audit to support its review based on an audit plan (ML23009B755) and documented its observations in an audit report dated January 19, 2023 (ML23093A215). X-energy submitted TR Revision 2, addressing the NRC staff's preliminary questions and the audit observations. During the review of TR Revision 2, the NRC staff identified additional questions (ML23277A274) and discussed them with X-energy in a public meeting (ML23346A120). X-energy also self-identified several items in TR Revision 2, that needed to be corrected. Subsequently, X-energy submitted TR Revision 3 (ML24047A308) that addresses the NRC staff's questions and its self-identified items. This safety evaluation is based on TR Revision 3.

The TR states that "the demonstration that the Xe 100 design bases satisfies these PDCs will be provided within the SARs of each application." Accordingly, the NRC staff will evaluate the acceptability of the Xe-100 design bases in satisfying the PDCs during the review of the individual applications.

Xe-100 Design Features

The Xe-100 design is a pebble bed HTGR with online fueling utilizing coated particle fuel embedded in a graphite pebble as the fuel element. The reactor operates in the thermal neutron spectrum and uses graphite as the moderator. It is designed to generate 200 megawatts thermal and produce high-quality, superheated steam for energy applications such as electricity production and industrial process heat. The standard Xe-100 plant consists of four units with some shared infrastructure and integrated plant systems. The key safety features include the inherent radionuclide retention capabilities of tri-structural isotropic (TRISO) fuel, which ensures the confinement of the radionuclides within the fuel under all normal and off-normal conditions, and no operator action or actively powered system is required to perform safety-significant functions. Reactivity control is performed through various mechanisms including a negative temperature coefficient of the fuel, controls rods, and shutdown rods. Helium is used as a medium for transporting thermal energy produced in the reactor to the steam generator. The helium is circulated through the pebble bed, reactor internals, cross vessel, and steam generator using two helium circulators. The Xe-100 design also incorporates passive design features to remove decay heat to achieve its intended safety functions.

Development approach for PDCs

In developing the PDCs for the Xe-100 design, X-energy used a two-pronged approach using both MHTGR-DCs in Appendix C of RG 1.232, and Xe-100 RFDCs and CDCs identified when implementing the NEI 18-04 method and NEI 21-07 guidance. When X-energy's proposed PDCs deviate from MHTGR-DCs, the rationale is provided in the TR describing how the changes relate to the safety basis of the Xe-100 design. The use of NEI 18-04 and NEI 21-07 as guidance in identifying RFDCs and CDCs also led X-energy to modify the MHTGR-DCs.

Appendix A of the TR contains the following tables:

- Table 1, "PDC Aligning with RSFs," contains proposed PDCs associated with RFDCs.

- Table 2, "PDC Aligning with NSRST PSFs," contains proposed PDCs associated with CDCs.

- Table 3, “PDC Associated with Normal Operations,” contains proposed PDCs associated with normal operations.

- Table 4, “PDC Associated with Special Treatments,” contains proposed PDCs associated with supporting the identification and implementation of special treatments to distinguish them from the category of ‘design criteria’ in RFDCs and CDCs.

- Table 5, “GDC and ARDC Screened as Not Applicable for MHTGRs based on RG 1.232,” contains those MHTGR-DCs screened, consistent with RG 1.232, Appendix C, for which X-energy proposes no PDCs.

- Table 6, “Xe-100 Principal Design Criteria,” contains X-energy’s proposed PDCs, its comparison with MHTGR-DCs, and the rationale for deviations from MHTGR-DCs.

Structure of Xe-100 PDCs

The seven-section structure of the proposed Xe-100 PDCs, shown below, closely follows that of the MHTGR-DCs in RG 1.232, Appendix C. The proposed Xe-100 PDCs generally retain the MHTGR-DC numbering scheme.

- Section I - Overall Requirements (Criteria 1-6)

- Section II - Multiple Barriers (Criteria 10-19)

- Section III - Reactivity Control (Criteria 20-29)

- Section IV - Heat Transport Systems (Criteria 30-46)

- Section V - Reactor Containment (Criteria 50-57)

- Section VI - Fuel and Radioactivity Control (Criteria 60-64)

- Section VII - Additional MHTGR-DC (Criteria 70-72)

2.2 Staff Evaluation

The NRC staff evaluated the TR to determine the acceptability of the proposed PDCs for the Xe-100 design. The NRC staff focused its review of the TR on the deviations from MHTGR-DCs in Appendix C of RG 1.232 and its bases, or rationale, as discussed in Appendix A of the TR. The deviations stem primarily from the following two key aspects:

(1) The Xe-100 design has aspects that are different from the MHTGR design on which MHTGR-DCs are based, and

(2) The Xe-100 PDCs are informed by the risk-informed and performance-based approach in RG 1.233.

For areas where X-energy did not deviate significantly from MHTGR-DCs in RG 1.232, no detailed evaluation is provided below because the rationale for the underlying safety basis documented in RG 1.232, remains applicable.

The Xe-100 design at the time of this TR review is considered preliminary and X-energy's implementation of the LMP process is in progress. The Xe-100 design may be updated as it is finalized and the ongoing LMP implementation for the design may result in changes to the design, both of which could result in a revision to the proposed PDCs described in the TR. Therefore, future licensing applicants referencing the TR must confirm that the PDCs in this TR remain appropriate for their design. In addition, if additional or revised PDCs are identified, those PDCs will be subject to the NRC staff's review independent of the TR. See item (1) in Section 3.0, "Limitations and Conditions."

The following summarizes the areas of importance and associated findings from the NRC staff's evaluation.

2.2.1 Use of the term "Safety-significant"

A set of proposed PDCs (e.g., PDCs 1-6) for Xe-100 uses the term "safety-significant" instead of the term "important to safety" used in RG 1.232. The use of the term "safety-significant" is consistent with RG 1.233, which endorses NEI 18-04 with clarifications. As stated in 10 CFR Part 50, Appendix A, SSCs that are classified as "important to safety" are those "that provide reasonable assurance that the nuclear power plant can be operated without undue risk to the health and safety of the public." The TR states that all safety-significant SSCs are classified as SR or NSRST, which is consistent with NEI 18-04 as endorsed in RG 1.233.

The NRC staff considers the use of the term "safety-significant," to be acceptable in the applicable Xe-100 PDCs since this term is equivalent to the term "important to safety" as used in the GDCs and RG 1.232 and is consistent with the guidance in NEI 18-04 as endorsed in RG 1.233 and NEI 21-07 as endorsed in RG 1.253.

2.2.2 Scope of LBEs for the proposed Xe-100 PDCs

In the TR, X-energy replaces the terms such as 'postulated accident' or 'accident conditions' used in MHTGR-DCs in RG 1.232 with those describing LBEs used in NEI 18-04. The LBEs in NEI 18-04 include Anticipated Operational Occurrences (AOOs), Design Basis Events (DBEs), Design Basis Accidents (DBAs) and Beyond Design Basis Events (BDBEs). Since the terms from RG 1.232 are not used in the NEI 18-04 methodology, use of the terms in NEI 18-04 is logical and helps clarify which LBEs need to be analyzed as part of the PDC scope.

However, the NRC staff notes that BDBEs are not included in the scope of the Xe-100 PDCs presented in this TR. One of the two SR SSC criteria of NEI 18-04 is that those SSCs relied on to perform the Required Safety Functions (RSFs) to prevent the frequency of any BDBE with consequences greater than the 10 CFR 50.34, "Contents of applications; technical information," dose limits from increasing into the DBE region and beyond the frequency-consequence (F-C) target in NEI 18-04, are classified as SR. In NEI 18-04, SSCs are identified as NSRST if they perform risk-significant functions or are identified as necessary for DID adequacy. An SSC is regarded as risk-significant if its PSF is either: 1) required to keep one or more LBEs inside the

F-C target based on mean frequencies and consequences or 2) if the total frequency of LBEs that involve failure of the SSC PSF contributes at least one percent to any of the LMP cumulative risk targets. According to NEI 18-04, the scope of PDCs should, in general, include BDBEs because safety-significant SSCs can be identified from BDBEs.

On this subject of BDBEs, the TR states that "Xe-100 design and supporting analyses demonstrate that 1) there are not any BDBEs with consequences greater than the 10 CFR 50.34 dose limits that could increase into the DBE region and beyond the F-C Target and 2) there are not any SSCs classified as NSRST that perform a risk-significant function, the Xe-100 PDC-RFDC and PDC-CDC scope does not require BDBEs to assure that appropriate design limits are not exceeded." The NRC staff makes the following two observations based on the X-energy's statement above:

(1) An SSC may be identified as NSRST if it is necessary for DID adequacy. Evaluation of DID adequacy is conducted for all safety-significant LBEs in NEI 18-04, which states, in Section 5.7, "Evaluation of LBEs Against Layers of Defense," that "a central element of the RIPB evaluation of DID is a systematic review of the LBEs against the layers of defense."

(2) The Xe-100 design is still preliminary at the time of this TR review and X-energy's implementation of the LMP process is in progress. The updated design and associated implementation of the LMP process can possibly identify SSCs that meet the SR or NSRST SSC criteria associated with BDBEs discussed earlier.

Given that the Xe-100 PDCs proposed in the TR may not represent a full set of PDCs for all SSCs that are important to safety, that is both SR and NSRST SSCs, additional PDCs may be identified for some SSCs related to BDBEs. Accordingly, the NRC staff acceptance of the scope of LBEs in this TR, including that there are no BDBEs, is conditioned on future license applicants referencing this TR, confirming that no safety-significant SSCs associated with BDBEs exist based on its design and implementation of the LMP process. See item (1) under Section 3.0 below for the condition of this TR approval related to this topic.

2.2.3 Owner Controlled Design Criteria (OCDCs) and PDCs for normal operations

X-energy's proposed PDCs (i.e., 2, 4,10, 13, 15, 19, 22, 26, 34, 44, 60, 61, and 64) include criteria associated with normal operations or conditions. In doing so, X-energy states in the TR that, while non-safety-related with no special treatment (NST) SSCs perform NST PSFs that maintain the plant within its normal operating envelope, NST SSCs are not classified as safety-significant SSCs according to the LMP process. X-energy uses OCDCs to designate these criteria for NST SSCs that are not required to be met during AOOs, DBEs, or DBAs. It maintains that the OCDCs associated with NST SSCs are not part of the Xe-100 design bases scope and therefore are not required to relate to PDCs as described in related regulatory requirements such as those in 10 CFR 50.34(a)(3)(ii). This use of OCDCs is not discussed in NEI 21-07, which discusses RFDCs and CDCs corresponding to SR and NSRST SSCs respectively.

The NRC staff finds X-energy's use of OCDCs for PDCs that correspond to NST SSCs is reasonable in that it distinguishes OCDCs from PDCs that correspond to SR and NSRST SSCs. The NRC staff also finds that X-energy's proposed PDCs maintain the phrase 'normal operations or conditions' from corresponding MHTGR-DCs. Therefore, the NRC staff finds that X-energy's proposed PDCs for normal operations or conditions are acceptable because the underlying basis provided by X-energy is sufficiently similar to the applicable basis in NEI 21-07, as endorsed in RG 1.232 and RG 1.253.

2.2.4 'Shall be designed' versus 'shall' or 'shall be provided'

Multiple PDCs proposed by the applicant (e.g., PDCs 13, 17, 26, and 34) replace RG 1.232 verbiage referring to the function of the SSCs (e.g., replacing "shall" or "shall be provided" with "shall be designed"). The NRC staff interprets these words as having the same effective meaning. From the NRC staff's perspective, a commitment to design to a certain standard also represents a commitment to provide that function in the as-built design. Therefore, the NRC staff finds that X-energy's proposed PDCs with these word changes are acceptable because they meet the underlying intent of the RG 1.232 design criteria.

2.2.5 Replacement of a single failure criterion with a reliability criterion

Xe-100 PDCs 17, 34, and 44 do not use the single-failure criterion language in RG 1.232. Instead, X-energy is using the approach described in NEI 18-04 as endorsed by RG 1.233. In Staff Position C.1.d of RG 1.233, the NRC staff determined that the approach described in NEI 18-04 is consistent with the Commission's staff requirements memorandum (ML031770124) approving the NRC staff's recommendation in SECY-03-0047, "Policy Issues Related to Licensing Non-Light-Water Reactor Designs" (ML030160002), to replace the single-failure criterion with a probabilistic (reliability) criterion. The NEI 18-04 methodology subjects the design to a reliability criterion and to an evaluation of DID adequacy based on assessments of event sequences. Because the approved methodology in NEI 18-04 addresses the safety basis associated with single failure in these PDCs, the NRC staff finds that the replacement of the single-failure criterion language in the corresponding MHTGR-DCs in RG 1.232 with a reliability criterion in these PDCs, is acceptable.

2.2.6 Use of functional containment concept

In RG 1.232, MHTGR-DCs 38-43 and 50-57 are screened as not applicable for MHTGRs because the MHTGR design does not include a pressure retaining reactor containment structure. The Xe-100 design also does not include a pressure retaining reactor containment structure. X-energy's proposed PDC 16, "Functional containment design," uses the language of MHTGR-DC 16 to outline the use of a functional containment method, which is defined as "a set of barriers taken together, that effectively limit the physical transport and release of radionuclides to the environment across a full range of normal operating conditions, AOOs, and accident conditions." The key aspects of MHTGR-DC 16 include the requirement for multiple barriers, controlling the release of radioactivity to the environment, and ensuring functional containment design conditions are not exceeded for as long as needed during postulated accidents.

X-energy's proposed PDC-RFDC 16 and PDC-CDC 16 represent a revision of MHTGR-DC 16 for functional containment. The proposed combination of design criteria specifies that multiple barriers (i.e., particles, pebbles, and the helium pressure boundary) control the release of radioactivity during AOOs, DBEs, and DBAs. Additionally, the proposed design criteria replaced the words “design conditions important to safety” from MHTGR-DC 16 with “design limit” to clearly articulate that a design limit related to the functional containment exists and cannot be exceeded. Further, X-energy considers the replaced terminology “design conditions” to refer to conditions under which RSFs and PSFs need to be performed. The NRC staff expects that the specific “design limit” will be developed in the context of the safety analyses used to support future licensing applications and will be evaluated for specific acceptability when those are reviewed. The NRC staff evaluated this terminology change and concluded that this is consistent with the meaning of MHTGR-DC 16 in RG 1.232.

The NRC staff determined that the proposed PDC-RFDC 16 and PDC-CDC 16 adequately specify the design requirements for a multi-layer functional containment that will ensure the capability to control the release of radionuclides to within acceptable levels. Therefore, the NRC staff finds the proposed PDC-RFDC 16 and PDC-CDC 16 to be acceptable as they apply to the Xe-100 design because they satisfy the underlying intent of MHTGR-DC 16 in RG 1.232. However, this safety evaluation makes no finding regarding the acceptability of any specific functional containment design limit(s) that will be used to demonstrate the adequacy of this approach to meet regulatory requirements and provide reasonable assurance of adequate protection of the public health and safety. The NRC staff expects that the future licensing submittal will address the establishment of these limits and how they will demonstrate conformity with regulatory requirements.

2.2.7 PDC 6, “Monitoring, Inspection, Testing, Surveillance”

In the TR, X-energy proposes PDC 6 as a single criterion to subsume monitoring, testing, inspection, and surveillance of safety-significant SSCs, which are collectively addressed in RG 1.232 by MHTGR-DCs 18, 31, 36, 37, 45, and 46. The NRC staff reviewed the proposed PDC and found that it specifies that all safety-significant SSCs will be designed to permit appropriate monitoring, periodic inspection, testing, and/or surveillances to ensure functional capability commensurate with the safety significance of the functions to be performed. This is consistent with the underlying intent of the related MHTGR-DCs in RG 1.232, and is therefore, acceptable.

2.2.8 PDC 11, “Reactor inherent protection”

X-energy states that the proposed PDC-RFDC 11 accomplishes some or all of the purposes associated with MHTGR-DCs 11, 12, and 26. Proposed PDC-RFDC 11 is informed by MHTG-DC 11, replacing the words “that contribute to reactivity feedback” with “with sufficient negative reactivity feedback characteristics,” deleting “of the prompt inherent nuclear feedback characteristics tends,” and adding a clause at the end requiring adequate control of heat generation, ensuring fuel performance and release limits are not exceeded during DBEs and DBAs, and ensuring specified acceptable radiological release design limits (SARRDLs) are not exceeded during AOOs. The changes do not materially affect the underlying safety purposes associated with MHTGR-DC 11, with the exception of the removal of the prompt feedback clause. In the context of the proposed PDC-RFDC 11, the NRC staff finds that the removal of the clause is acceptable because the requirements to provide sufficient negative reactivity feedback, control heat generation and ensure that the fuel and radionuclide release limits envelop the narrower statement regarding “prompt inherent nuclear feedback characteristics.”

X-energy indicates that the proposed PDC-RFDC 11, fulfills the underlying intent of MHTGR-DC 12 as well. MHTGR-DC 12 requires that the core and associated protections systems be designed to ensure that power oscillations that can result in conditions exceeding design limits are not possible or can be reliably and readily detected and suppressed. The NRC staff determined that MHTGR-DC 12 is sufficiently generic such that a largely comparable PDC or RFDC would be compatible with the X-energy approach. The proposed approach to use a higher level, more general PDC-RFDC 11 appears to satisfy a similar underlying safety purpose, and is therefore found acceptable by the NRC staff, based on the following assumptions. First, the clause following "net effect…" in the proposed PDC-RFDC 11, encompasses the same design limits associated with MHTGR-DC 12. The language regarding power oscillations is not specific in the proposed PDC-RFDC 11, but the NRC staff interprets that "sufficient negative reactivity feedback characteristics" and "net effect" language, coupled with the commitment provided in the basis stating, "fuel performance and radionuclide release limits will be demonstrated with safety analysis," is sufficient to account for power oscillations, if present (they are not anticipated). Second, use of "in the power operating range" has the potential to complicate the applicability of PDC-RFDC 11 to the scope of MHTGR-DC 12. If present, power oscillations or reactivity upsets may occur outside the power operating range. Accordingly, the NRC staff's acceptance of PDC-RFDC 11 is conditioned on demonstration in a safety analysis that will cover the full scope of the operating range, DBE, and DBA conditions for the final design. See item (2) under Section 3.0 below for the condition of this TR approval related to this topic.

2.2.9 PDC 14, "Reactor helium pressure boundary"

In its proposed PDC 14, X-energy deletes the words "of rapidly propagating failure, of gross rupture" from the corresponding MHTGR-DC 14. This function is addressed as part of PDC 70, which is evaluated further below. X-energy deletes the words "ingress of air, secondary coolant, or other fluids" from MHTGR-DC 14 and replaces them with "moisture ingress." X-energy states that "secondary coolant" is water and thus is addressed by 'moisture' in the proposed PDC, which the NRC staff finds reasonable. X-energy also states that "no risk significant AOOs, DBEs, or DBAs were identified with unacceptable ingress of air or other fluids." Because the Xe-100 design development is still ongoing, the NRC staff's acceptance of this PDC is conditioned on the verification of this position during the NRC staff's review of AOOs, DBEs, and DBAs as part of a future license application referencing this TR. See item (3) under Section 3.0 below for the condition of this TR approval related to this topic.

2.2.10 PDC 17, "Electric power systems"

For PDC 17, X-energy retains only the portion of MHTGR-DC 17 that is applicable to the NSRST PSFs. The Xe-100 design, as described, does not include any SR electrical power source and does not include electrical power systems that perform any risk-significant functions or RSFs. On that basis, the NRC staff finds that the proposed PDC 17 (PDC-CDC 17) is acceptable because it conforms with applicable portions of MHTGR-DC 17 in RG 1.232 and meets the underlying intent of the RG in the context of NSRST PSFs performed by electric power systems. However, approval of PDC 17 is conditioned on item (1) in SE Section 3.0 to ensure that the stated basis for acceptance remains applicable as the design is finalized.

2.2.11 PDC 26, "Reactivity control systems"

MHTGR-DC 26 combines the underlying purposes associated with GDCs 26 and 27 into four functions that are intended to be met by two diverse means (at a minimum).

X-energy proposes a PDC (PDC 26), two RFDCs (PDC-RFDCs 11 and 26), a CDC (PDC-CDC 26) and an OCDC (PDC-OCDC 26), to accomplish the same purposes as MHTGR-DC 26. Proposed PDC-RFDC 26 requires that the reactor be designed to provide movable poisons that can achieve and maintain safe shutdown during DBEs and DBAs, satisfying a portion of Element (3) of MHTGR-DC 26. PDC-RFDC 11, discussed previously, contributes to the other portion of Element (3), to ensure core cooling. Proposed PDC-CDC 26 requires a diverse means of reactivity insertion to assure design limits are not exceeded and safe shutdown is achieved and maintained during AOOs. Normal operations are covered under PDC-OCDC 26, to satisfy portions of Element (1) and Element (2) of MHTGR-DC 26, which appropriately aligns with the discussion in SE Section 2.2.3 regarding OCDCs. PDC-CDC 26 and PDC-OCDC 26 also specify that normal operations, AOOs, DBEs, and DBAs are to be covered by two diverse means, which satisfies other relevant portions of Element (1) and Element (2). Element (4) is satisfied by proposed PDC 26. Accordingly, the NRC staff finds that the proposed PDC 26 is acceptable because it, along with PDC 11, addresses the underlying intent of MHTGR-DC 26 in RG 1.232. The NRC staff conditions this acceptance on the implementation of the NEI 18-04 methodology applied to the reactivity control function as discussed in item (1) in Section 3.0.

2.2.12 PDC 34, "Residual heat removal"

X-energy's proposed combination of PDC-RFDC 34, PDC-CDC 34, and PDC-OCDC 34 represents a substantial revision to MHTGR-DC 34. The stated purposes of MHTGR-DC 34 are to provide adequate decay heat removal for normal operations and AOOs such that fuel and helium pressure boundary limits are not exceeded, to provide effective cooling in the event of accidents, and provide system functions in the event of single failure. The proposed PDC-RFDC stipulates a passive system be provided to ensure SARRDLs are not exceeded during DBEs and DBAs, while the proposed PDC-CDC and PDC-OCDC state that an active means shall be provided for the same function for AOOs and normal operations, respectively. Removal of the single failure criterion is discussed above and is acceptable in the context of the implementation of the NEI 18-04 methodology. Separation of the criteria into PDC-RFDC, PDC-CDC, and PD-OCDC is acceptable because the underlying functions associated with MHTGR-DC 34, maintaining fuel design limits, remain for all states of operation. Section 2.2.3 of this SE discusses the use of OCDCs. X-energy states that the function associated with helium pressure boundary maintenance is provided by proposed PDC 70, which is evaluated below. Therefore, the NRC staff finds X-energy's proposed PDC 34 acceptable, because it conforms with the underlying purposes of MHTGR-DC 34 in RG 1.232.

2.2.13 PDC 70, "Reactor vessel and reactor system structural design basis"

X-energy's proposed PDC-RFDC 70 uses MHTGR-DC 70 with changes. Proposed PDC-RFDC 70 aligns with RSF 1.4.1, "Maintain HPB and Core Geometry," which meets the intent of MHTGR-DC 70 and the "low probability of rapidly propagating failure" portion of MHTGR-DC 14.

The proposed PDC-RFDC 70 states that the helium pressure boundary shall be designed such that the reactor vessel and reactor system integrity is maintained and that there is a low probability of rapidly propagating failure during DBEs and DBAs. It stipulates that the geometry for passive removal of residual heat from the reactor core to the ultimate heat sink is maintained and continues to permit sufficient insertion of the neutron absorbers such that reactor inherent protection is provided for reactor shutdown. The NRC staff finds that the proposed PDC-RFDC 70 is acceptable because it reflects the Xe-100 design, while still meeting the underlying purposes for the associated RSFs of pertinent portions of MHTGR-DCs 14 and 70 in RG 1.232.

2.2.14 PDCs with no changes from MHTGR-DCs

For the following PDCs, X-energy proposed using the corresponding MHTGR-DCs with no changes as Xe-100 PDCs: 23, 24, 25, 62, and 63. The NRC staff determined that the Xe-100 design is sufficiently similar to the assumed design for the MHTGR-DCs and that the intent and underlying bases for approving the MHTGR-DCs also apply to the Xe-100. As such, the NRC staff finds these PDCs acceptable.

2.2.15 GDCs and ARDCs screened as 'Not Applicable for MHTGRs'

The NRC staff evaluated Table 5 in Appendix A of the TR and found that the GDCs and ARDCs screened as not applicable (i.e., 27, 33, 35, 38-43 and 50-57), are acceptable because the screening and its rationale in the table are consistent with those for MHTGR-DCs in RG 1.232, Appendix C according to the Xe-100 design.

3.0 LIMITATIONS AND CONDITIONS

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

(1) X-energy is requesting approval for the proposed PDCs based on a preliminary design and the LMP implementation at the time of the TR submittal. Xe-100 design changes and associated LMP implementation could necessitate a revision to the proposed PDCs described in the TR. Therefore, future licensing applicants referencing the TR must confirm that the PDCs in this TR remain appropriate for its design. In addition, if additional or revised PDCs are identified that are not within the scope of what is approved in this TR, those PDCs will be subject to further NRC staff review.

(2) For PDC-RFDC 11, X-energy used the words "in the power operating range". This phrase has the potential to complicate the applicability of PDC-RFDC 11 to the scope of MHTGR-DC 12. Power oscillations or reactivity upsets that may occur outside the power operating range should be assessed. Accordingly, the NRC staff conditions the acceptance of PDC-RFDC 11 on confirmation by future licensing applicants referencing this TR that applicable safety analyses cover the full scope of the operating range, DBE, and DBA conditions for the final design.

(3) For PDC 14, X-energy is proposing to delete the words "ingress of air, secondary coolant, or other fluids" from MHTGR-DC 14 and replace it with the words "moisture ingress". For justification, X-energy states that "no risk significant AOOs, DBEs, or DBAs

were identified with unacceptable ingress of air or other fluids". This cannot be verified at the present state of the Xe-100 design. Accordingly, the NRC staff conditions the acceptance of this PDC on the NRC staff's review of AOOs, DBEs, and DBAs as part of a future license application referencing this TR.

4.0 CONCLUSION

Based on the above evaluation, the NRC staff concludes that X-energy has considered each of the design aspects presented in RG 1.232 in light of RG 1.233 and RG 1.253, and provided a sufficient set of PDCs that are appropriate for establishing requirements for the Xe-100 design, subject to the limitations and conditions listed in this SE. Subject to these limitations and conditions, these PDCs establish the necessary design, fabrication, construction, testing, and performance design criteria for safety-significant SSCs to provide reasonable assurance that the Xe-100 design could be operated without undue risk to the health and safety of the public. Revision 3 of the subject TR is therefore suitable for referencing in future licensing applications for the Xe-100 design.

5.0 REFERENCES

1. Letter from T. Chapman to the U.S. Nuclear Regulatory Commission (NRC), "Submission of X Energy, LLC (X-energy) Xe-100 Principal Design Criteria Licensing Topical Report," dated July 13, 2022 (ML22195A260).

2. NRC, "U.S. Nuclear Regulatory Commission Preliminary Questions regarding X Energy LLC Topical Report: Xe-100 Risk-Informed Performance-Based Licensing Basis Development," dated November 2021 (ML21312A478).

3. Letter from T. Chapman to the NRC, "X Energy, LLC (X-energy) Responses to "NRC Staff's Preliminary Questions on the NRC Assessment of the X Energy, LLC Xe-100 Principal Design Criteria Licensing Topical Report,"" dated December 30, 2022 (ML22364A293).

4. NRC, "Audit Plan for the Xe-100 Principal Design Criteria Licensing Topical Report," dated January 19, 2023 (ML23009B755).

5. NRC, "Regulatory Audit Report: Xe-100 Principal Design Criteria Licensing Topical Report," dated April 12, 2023 (ML23093A215).

6. NRC, Regulatory Guide, RG 1.232, "Guidance for Developing Principal Design Criteria for Advanced (Non-Light Water) Reactors," dated April 30, 2018 (ML17325A611).

7. NRC, Regulatory Guide, RG 1.233, "Guidance for a Technology-Inclusive, Risk-Informed, and Performance-Based Methodology to Inform the Licensing Basis and Content of Applications for Licenses, Certifications, and Approvals for Non-Light Water Reactors," dated June 30, 2020 (ML20091L698).

8. Nuclear Energy Institute, NEI 18-04, Revision 1, "Risk-Informed Performance-Based Guidance for Non-Light Water Reactor Licensing Basis Development," dated August 29, 2019 (ML19241A472).

9. Nuclear Energy Institute, NEI 21-07, Revision 1, "Technology Inclusive Guidance for Non-Light Water Reactors, Safety Analysis Report Content: For Applicants Using the NEI 18-04 Methodology," dated February 2022 (ML22060A190).

10. NRC, RG 1.253, Revision 0, "Guidance for a Technology-Inclusive Content-of-Application Methodology to Inform the Licensing Basis and Content of Applications for Licenses, Certifications, and Approvals for Non-Light-Water Reactors," dated March 22, 2024 (ML23269A222).

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Date: October 24, 2024