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

**X ENERGY, LLC – SAFETY EVALUATION OF XE-100 TOPICAL REPORT: TRANSIENT AND SAFETY ANALYSIS METHODOLOGIES FRAMEWORK, REVISION NO. 1 (EPID NO. L-2021-TOP-0023)**

**SPONSOR AND SUBMITTAL INFORMATION**

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**Project No.:** 99902071

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**Submittal Agencywide Documents Access and Management System (ADAMS) Accession No.:** ML21288A173

**Brief Description of the Topical Report:**

X Energy, LLC (X-energy) is in the process of developing a high-temperature gas-cooled reactor called the Xe-100, which uses TRI-structural ISOtropic (TRISO)-coated Uranium Oxycarbide fuel in pebble form. The topical report (TR) is part of a pre-license application series of reports X-energy expects to submit for U.S. Nuclear Regulatory Commission (NRC) staff review to support its upcoming license application for the Xe-100 design.

The TR provides a description of the proposed plan and approach to develop analysis and evaluation methods for the Xe-100 reactor design safety analysis. X-energy's proposed approach is based on Regulatory Guide (RG) 1.203, "Transient and Accident Analysis Methods," Revision 0 (ML053500170), and draws in elements of the overall plant methodology from Nuclear Energy Institute (NEI) 18-04, Revision 1, "Risk-Informed Performance-Based Technology Inclusive Guidance for Non-Light Water Reactor Licensing Basis Development" (ML19241A336 (package)), which was reviewed and endorsed by the NRC staff in RG 1.233, "Guidance for a Technology-Inclusive, Risk-Informed, and Performance-Based Methodology to Inform the Licensing Basis and Content of Applications for Licenses, Certifications, and Approvals for Non-Light Water Reactors," Revision 0 (ML20091L698). The TR also describes at a high level what computer codes an applicant referencing the TR will use to model the Xe-100 in the safety analyses and provides sample results for two transient evolutions. X-energy acknowledges that the basis provided in the TR does not represent the complete transient and accident analysis methodology that will be needed to support a licensing application. X-energy

states that updates will be made either as revisions to the TR or in other supplemental licensing requests related to the TR.

Additional details regarding the submittal can be found in the document located at the ADAMS Accession No. identified above.

## REGULATORY EVALUATION

### Regulatory Basis:

Title 10 of the *Code of Federal Regulations* (10 CFR) 50.34(a)(4) and (b)(4) apply to applicants for construction permits and operating licenses, respectively. In part, these sections require an analysis and evaluation of the design and performance of structures, systems, and components (SSCs) of the facility with the objective of assessing the risk to public health and safety resulting from operation of the facility and including determination of the margins of safety during normal operations and transient conditions anticipated during the life of the facility, and the adequacy of SSCs provided for the prevention of accidents and the mitigation of the consequences of accidents. Similar regulatory requirements exist for design certification applications, combined license applications, standard design approvals, and manufacturing licenses (10 CFR 52.47(a)(4), 10 CFR 52.79(a)(5), 10 CFR 52.137(a)(4), and 10 CFR 52.157(f)(1) respectively).

Also, 10 CFR 50.34(a)(3)(i) requires, in part, that an applicant for a construction permit to build a power reactor provides principal design criteria (PDC) for the facility. Similar regulatory requirements exist for design certification applications, combined license applications, standard design approvals, and manufacturing licenses (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) respectively). The PDC establish requirements for SSCs that are safety-significant. The general design criteria (GDC) in Appendix A to 10 CFR Part 50 provide guidance for establishing PDC for non-light-water reactor (non-LWR) designs, and numerous GDC, including but not limited to 10, 26, and 27 (Reactor design, Reactivity control system redundancy and capability, and Combined reactivity control systems capability, respectively), rely on an ability to adequately assess fuel performance and reactivity margin.

An adequate analysis methodology is fundamental in providing the basis for the specific analyses and evaluations to be submitted in order to satisfy these regulations. Ultimately, the TR is expected to form a portion of the basis for meeting these regulations, and this safety evaluation (SE) documents the NRC staff review of the technical acceptability of the TR within the requested scope.

## TECHNICAL EVALUATION

### Methodology Overview

The scope of the TR applies broadly to the collection of evaluation and analysis methodologies that X-energy plans to use to support a future safety analysis report submittal as part of a license application. At present, the TR provides a general, high-level description of the planned safety analysis methodology; notably, the NRC staff understands the report does not provide the details of specific codes that will be used to perform safety analyses or how specific analyses was categorized/performed. X-energy plans to provide this information in the future for NRC staff review, whether as an update to the TR or separate licensing submittals.

The NRC staff has evaluated much of the TR through the lens of RG 1.203, which provides an acceptable framework for the evaluation model development and assessment process (EMDAP). Because of the direct linkage to the methodology development and the nascent state of X-energy's methodology, NRC staff findings will be provided on a case-by-case basis below. There are six elements or principles of an EMDAP outlined in RG 1.203. The TR provides a detailed discussion of four of these elements, and the other two are discussed in the TR at a high level. All six elements of the EMDAP are discussed below in this SE.

As stated in the regulatory evaluation above, applicants are required to provide PDC for their facility. RG 1.232, "Guidance for Developing Principal Design Criteria for Non-Light Water Reactors," Revision 0 (ML17325A611), provides guidance to advanced reactor applicants for developing these PDC, though X-energy states it plans to supplement this guidance with insights from NEI 21-07, "Technology Inclusive Guidance for Non-Light Water Reactors," Revision 0 (ML21250A378), and NEI 18-04 and development of the PDC "should not make a material difference in the development of [evaluation models] and the performance of the safety analyses." The NRC staff provisionally agrees with this assessment – there is a minimum for what constitutes an acceptable evaluation model, independent of the requirements imposed by the PDC – but the NRC staff notes that the evaluation methodology must be capable of modelling the relevant phenomenon to demonstrate the PDC and other relevant regulations are satisfied.

X-energy plans to use the NEI 18-04 framework (endorsed as clarified in RG 1.233) to define portions of its licensing basis and has submitted a separate TR that was approved by the NRC staff (ML22308A197). Accordingly, use of that methodology will not be evaluated in this SE except where the described use of that methodology would directly interact with the evaluation model. The NRC staff performed an audit as part of the TR review and development of this SE. The NRC staff's audit summary is documented in the "Report for the Regulatory Audit Regarding X Energy LLC's Xe-100 Licensing Topical Report Transient and Safety Analysis Methodologies Framework," dated September 28, 2022 (ML22235A777).

**Element 1: Determine requirements for the evaluation model**

The first element of developing an evaluation model is to determine what requirements are to be satisfied by the model in order to focus the model on the appropriate phenomena for the design. For the Xe-100 design, X-energy has initially chosen to select the specific transient analysis through use of the probabilistic risk assessment and the NEI 18-04 methodology as applied to the overall design. This process is ongoing, as discussed in the TR. X-energy has not provided all of the design details at this stage, but states that an individual reactor will be a 200 megawatt-thermal helium-cooled, TRISO-fueled pebble bed reactor module connected to a steam generator.

Use of the EMDAP involves refining a scope for the analyses to be used in a licensing application and ensuring target parameters can be calculated with sufficient accuracy. Once the target and scope for the analyses have been specified and these can be linked to requirements, developing the evaluation model involves specifying figures of merit (FOMs) for the analysis. X-energy states that it plans to use NEI 18-04 and RG 1.232 in concert to derive the PDC and FOMs for those PDC. X-energy specifies high level FOMs for anticipated operational occurrences (AOOs) and that design basis accidents will have deterministic FOMs, but the development of event-specific FOMs is still in progress.

The NRC staff audited calculation XE00-V-S1ZZ-ZZZ-A, "Preliminary Figure of Merit Calculation Procedure for Xe-100 Safety Analysis Report." The NRC staff's initial review of the calculation indicated the applicant is using regulatory dose limits and other associated radiological design objectives to develop transient-specific FOMs, which X-energy states are still being developed. X-energy does note that "at this stage in the Xe-100 development program, the [probabilistic risk assessment] PRA and safety analysis for the Xe-100 conceptual design were still in early-stage development and therefore the progression of events for target accidents in the Xe-100 reactor and specific FOMs were not finalized."

Initial review by the NRC staff indicated that no obvious errors were made in the selection of phenomena to model and appropriate FOMs could be derived, but models and event selection were not sufficiently finalized for NRC staff to make detailed findings. Accordingly, final approval of a transient and accident methodology will require development of an appropriate set of FOMs for the full spectrum of events to be modeled for the X-energy design. This represents **Limitation 1** on the TR.

The next steps in the process are to identify systems, components, and other aspects of the design that must be modeled and to identify and rank key phenomena and processes for the design. The TR states, in part, that "[a]t this stage of Xe-100 development, the majority of SSCs that require modeling have been identified at the functional level and are being more fully developed through the preliminary design." X-energy provides examples of analyses that begin to characterize what SSCs and aspects of the design are relevant for two scenarios in TR appendices B and C, noting that these analyses are preliminary in nature. The NRC staff reviewed the information in these appendices and found them illustrative as examples, though the NRC staff expects additional variables and detail on other aspects of the system would be provided as part of a final analysis methodology or application submittal.

The NRC staff audited report K-640207/RP/0003, "XE-100 Phenomena Identification and Ranking Tables" (PIRT). X-energy has produced an internal PIRT that is comprehensive and included experts internal to X-energy and from national labs and academia. The PIRT appears reasonable and characterizes knowledge and importance levels for many of the phenomena of concern for the design. However, there is still substantial uncertainty (much of which is acknowledged by the applicant) in many areas due to a lack of design detail.

Given this, the NRC staff finds the TR provides a foundation for developing evaluation model requirements but refined final requirements should be provided as part of a future application related to the evaluation model (whether an update to the TR or a design implementing such a model). Specifically, a final PIRT (or functionally similar tool) and list of relevant SSCs and phenomena to be modeled, along with relevant assumptions, should be available in order to review the final evaluation model. This represents **Limitation 2** on the TR.

**Element 2: Develop an assessment base**

Element two in developing an evaluation model relates to developing an assessment base for the tool(s) used as part of the evaluation model. Specifically, model developers should specify objectives for the assessment base, perform scaling analysis and identify similarity criteria, identify appropriate existing data and perform testing so that adequate data is available for the model, evaluate any distortions or scaling issues associated with the testing or data, and determine uncertainties as applicable.

As stated in the TR, “specific code selections for certain event sequence evaluation models are still under evaluation,” and this information will be captured and submitted separately supporting the documentation for the codes that will be used for the Xe-100 evaluation model. Therefore, this element represents an open item for this evaluation model, and future submittals supporting the codes that make up the evaluation model should make verification and validation assessment information available to the NRC staff as part of those submittals. This represents **Limitation 3** on the TR.

Based on information audited by the NRC staff, it is understood that some code-to-code coupling may be used by X-energy in the final evaluation model. The NRC staff notes that the coupled computer codes, if used, should also be assessed as used in the safety analysis – the codes should be individually assessed, and an integrated assessment of the coupled code system as used in the evaluation model should also be performed.

**Element 3: Develop the evaluation model**

The third element in an EMDAP is to develop the evaluation model and it involves three steps: establish an evaluation model development plan, establish an evaluation model structure, and develop or incorporate closure models into the code(s) used. The NRC staff audited a collection of documents, including code manuals, preliminary evaluation models, and PIRTs for various phenomena of interest. These documents, though preliminary in nature, provide an acceptable initial framework for developing an evaluation model. Provided an applicant satisfies **Limitations 3 and 4** through additional submittals or updates to the TR, no additional conditions are needed for this element. The NRC staff notes that this element would need to be satisfied for each code or model employed for use in the safety analysis.

**Element 4: Assess the adequacy of the evaluation model**

The NRC staff was unable to reach any finding related to the adequacy of the evaluation model because, as stated in the TR, “[d]etailed information for Steps 13-20 has not been fully developed for the Xe-100 evaluation model during the Conceptual Design phase.” Steps 13-20 are those associated with element four of the EMDAP in RG 1.203 and are listed in TR section 3.2.1.4. The TR states that X-energy will provide this information for NRC staff review as part of future submittals as the design develops. In order to make a finding regarding adequacy of the evaluation model, an applicant needs to furnish adequate information related to the capability and applicability of the model. This represents **Limitation 4** on the TR.

**Other Elements Considered**

RG 1.203 provides additional items necessary in developing an acceptable EMDAP, which are to follow an appropriate quality assurance (QA) protocol and to provide comprehensive, accurate, and up to date documentation. At the time of the NRC staff review of the TR, these steps were underway for the preliminary analysis that was provided as part of the TR and audited by the NRC staff. These steps are ongoing requirements, however, and based on the relative maturity of the X-energy EMDAP and the limitations associated with this SE, the NRC staff can make no finding related to these items, as any such finding would no longer be valid for the updated submittal and would require re-review. The NRC staff notes that this initial review did not identify any obvious deficiencies in the QA and documentation procedures established for the methodology thus far.

X-energy's use of the EMDAP, as considered in the TR, reflects a disconnect between the traditional evaluation model development process and the availability of design information and validation data that may be available at various stages in the design process. This SE attempts to bridge some of that disconnect by imposing limitations on the TR, but the NRC staff notes that the EMDAP is a holistic process intended to provide confidence that the model adequately captures the phenomena that occur in the design (more specifically, that could occur during the actual progression of events of the safety analysis). To some extent, consideration of elements 2, 3, and 4 was given by X-energy based on the information audited by the NRC staff, but these steps have yet to be performed sufficiently to consider the evaluation model developed. In effect, this SE documents the NRC staff finding that that X-energy is at an intermediate stage in the EMDAP and no serious errors were apparent, but substantial additional work will be required to finalize the evaluation model. The NRC staff notes that the final EMDAP has historically been a backwards-looking step to retroactively confirm code and design decisions and is used to independently confirm the adequacy of the models. Given the maturity of the EMDAP as put forth in the TR, the NRC staff expects X-energy to continue refining the EMDAP as design details are finalized and additional experimental data becomes available.

The NRC staff reviewed the examples of the safety analysis implementation provided in the appendices to the TR. **[[**

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Transient scenarios were initialized from a steady-state condition that was based on a run-in up to an effective equilibrium core. **[[**

**]]** The NRC staff makes no finding on the run-in analysis based on the preliminary nature, but considers the analysis effective for its intended purpose, subject to the conditions assumed for the analysis, which would need to be operationally restricted for the final design.

**[[**

**]]** The NRC staff considers the analyses an effective preliminary demonstration of the code suite. Due to the aspects of the code considered non-final or yet to be demonstrated, including aspects related to the assessment base and model adequacy for the specific phenomena and aspects of the design being modeled, the NRC staff makes no findings on the adequacy of the analyses themselves, and views them as an illustrative example of the preliminary methodology capabilities.

**X-energy Plant Modeling**

Safety analysis entails the use of computer code models for various analysis ends. The TR states X-energy plans to use NEI 18-04 and NEI 21-07 to develop the events presented in a future application. Section 3.6 of the TR states, in part, that "[t]hese methods do not require deterministic analyses to be performed for AOOs, Design Basis Events (DBEs), and Beyond Design Basis Events (BDBEs)." While this statement is true on its face, deterministic analyses are better characterized by their input conditions and assumptions, and the models and methodology should not be considered "deterministic" in the sense that entirely separate models and methods are required for the aforementioned event classes. Some level of event characterization and analysis is required for context for analyses presented as part of the final application (and may differ based on how various events are categorized by X-energy as part of the NEI 18-04 methodology).

Section 4 of the TR provides a high-level description of the modeling approach planned for the Xe-100. X-energy states a mechanistic source term, neutronics, kinetics, and thermal-hydraulics system code are planned to be used as part of the analytical approach, which is outlined in TR figure 5. Specific Xe-100 system characteristics, especially those pertaining to the neutronic and reactivity behavior, are detailed in TR section 4.3.2. Notably, proprietary design restrictions and design choices (in TR section 4.3.2.1) yield key safety parameters **[[**

**]]** The NRC staff is not making a finding on these safety characteristics for two reasons: presently, it would be better to characterize these as design goals, based on certain non-final aspects of the design and the NRC staff does not want to impose limitations in the TR on these aspects based on the information presented; and X-energy did not request review and approval of these areas, in most cases stating future work was to be performed as part of a future submittal or as part of "the next phase of the analysis."

The NRC staff audited various preliminary code documents and analyses related to these methods, and as part of the review, the NRC staff did not find any obvious flaws with the methods or their proposed use cases. However, the NRC staff did encounter a number of areas where a lack of design detail, insufficient model validation data, or both would prevent the applicant from using the proposed methodology as it exists right now. Fulfilling the limitations on the TR for specific codes and/or the methodology as a whole would resolve these gaps.

**Portions of the Topical Report not addressed by this Safety Evaluation**

While use of an adequate QA program (e.g., one that conforms with 10 CFR Part 50 Appendix B, to the extent it is applicable to the activities in question) is integral to the EMDAP as described in RG 1.203, evaluation of the QA procedures themselves is outside the scope of this SE and is performed as part of other NRC oversight activities at various stages of the licensing process. As such, use of the QA program as described in section 5 is appropriate, but the NRC staff did not review the QA program or QA procedures cited in section 5 of the TR directly as part of this SE, and instead looked at them to ensure a QA program was in effect over the other documents reviewed.

## LIMITATIONS

Final approval of a transient and accident methodology (or a portion of the methodology) will require development of additional information as noted below. An applicant may reference the TR for use as applied to the applicant's analysis only if the applicant demonstrates compliance with the following limitations and conditions:

1. An appropriate set of FOMs, justified for the full spectrum of events to be modeled for the X-energy design will need to be provided. This is likely to require sufficient design finalization such that scenario classes and operational regimes can be identified or bounded.
2. A final PIRT (or functionally similar tool) and list of relevant SSCs and phenomena to be modeled, along with relevant assumptions, should be made available as part of a future submittal related to the TR in order to facilitate review of the final evaluation model.
3. Adequate verification and validation assessment information should be made available to the NRC staff as part of future submittals supporting the codes that make up the evaluation model. This verification and validation information should be justified to reasonably bound the operational envelope for the design for any applicant referencing the TR. To the extent that the computer codes are coupled to one another, the verification and validation of the coupled configuration should also have adequate verification and validation associated with the configuration exercised as used for the safety analysis.
4. In order to link the transient and accident analysis methodology to the design itself, an applicant utilizing the TR needs to justify the use of the model for the design. This justification must discuss the capability of the model in the context of what is needed to appropriately represent the design and discuss how the model is applicable to the design, including consideration of system interactions occurring in the design, system conditions (which may affect the applicability of models or validation data). Uncertainties associated with the evaluation model and the validation data should be discussed in accordance with RG 1.203.

## CONCLUSION

Based on the above discussion, the NRC staff concludes that X-energy has provided an adequate plan for developing an evaluation model to be used for transient and accident safety analysis. Specifically, the steps and plan elements appear appropriate and indications from the NRC staff audit of documents provided are that the approach taken by the applicant is sound and conforms with RG 1.203. However, detailed design development is still underway and numerous aspects of the proposed methodology are not yet sufficiently finalized for the NRC staff to make findings that could support a finding of acceptability for a safety analysis methodology. Accordingly, the TR is subject to the limitations and conditions noted above and cannot be used by itself as an acceptable evaluation methodology. Based on the information provided in the TR request, the NRC staff finds the proposed approach is reasonable for continued safety analysis methodology development. The NRC staff will make a final determination of the acceptability of the transient and accident analysis methodology when the complete, detailed design and approach, including applicable testing, is completed and incorporated as part of submittals to the NRC for review as part of future licensing activities referencing or including the TR.

## REFERENCES

None.

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