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28 February 2022

2022-XE-NRC-004
XE00-Z-Z-Z-Z-Z-X-003622

Project No. 99902071

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, D.C. 20555-0001

Submission of X Energy, LLC (X-energy) Responses to Requests for Additional Information for Topical Report, "TRISO-X Pebble Fuel Qualification Methodology"

References: (1) Letter from M. van Staden to Nuclear Regulatory Commission dated April 30, 2021, "Submission of X Energy, LLC (X-energy) Xe-100 Topical Report: TRISO-X Pebble Fuel Qualification Methodology" (ML21120A334)

(2) Letter from T. Chapman to Nuclear Regulatory Commission dated September 2, 2021, "Submission of X Energy, LLC (X-energy) Xe-100 Topical Report: TRISO-X Pebble Fuel Qualification Methodology, Revision 2" (ML21246A289)

(3) Email to X Energy LLC, "Transmittal of Requests for Additional Information – Xe-100 Topical Report: TRISO-X Pebble Fuel Qualification Methodology" (ML21334A230)

In Reference (1), on April 30, 2021, X Energy, LLC (X-energy), submitted the Topical Report, "TRISO-X Pebble Fuel Qualification Methodology." Based on NRC feedback, the topical report was revised, and, in a letter dated September 2, 2021, X-energy submitted Revision 2 of the Topical Report in a proprietary and non-proprietary version (Reference 2). This topical report provides information related to the methodology for qualification of X-energy's TRISO-X coated-particle fuel and fuel pebbles for use in the Xe-100 reactor design.

On December 2, 2021, NRC issued Requests for Additional Information (RAIs) via email (Reference 3) and discussed with NRC staff on December 1, 2021, and February 10, 2022. X-energy's responses to these RAIs are attached in Enclosure 1 of this letter.

This submittal contains proprietary information, and, as such, we are requesting that this information be withheld from public disclosure in accordance with 10 CFR 2.390, "Public inspections, exemptions, request for withholding," paragraph (a)(4). Enclosure 1 is the Proprietary version of the responses which contains non-redacted sensitive information. An affidavit providing the basis for this request is provided in Enclosure 2. Enclosure 3 is the non-proprietary version of the responses.

If you have any questions or require additional information, please contact Ingrid Nordby at inordby@x-energy.com.

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Sincerely,

Travis Chapman
U.S. Licensing Manager, Xe-100 Program
X Energy, LLC

cc:
X Energy, LLC
George Vanderheyden
Steve Miller
Martin van Staden
Peter Pappano

Nuclear Regulatory Commission
William Kennedy
Lucieann Vechioli-Feliciano
Michael Orenak

Enclosures:
1) Responses to Requests for Additional Information for Topical Report, "TRISO-X Pebble Fuel Qualification Methodology" (Proprietary)
2) Affidavit
3) Responses to Requests for Additional Information for Topical Report, "TRISO-X Pebble Fuel Qualification Methodology" (Non-Proprietary)

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Enclosure 1
X Energy, LLC
Responses to Requests for Additional Information for X-energy Topical Report,
"TRISO-X Pebble Fuel Qualification Methodology"
(Proprietary)

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Enclosure 2
Affidavit

X Energy, LLC
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Affidavit Supporting Request for Withholding from Public Disclosure (10 CFR 2.390)

I, Travis A. Chapman, Manager, U.S. Licensing, Xe-100 Program, of X Energy, LLC (X-energy) do hereby affirm and state:

1. I am authorized to execute this affidavit on behalf of X-energy. I am further authorized to review information submitted to or discussed with the Nuclear Regulatory Commission (NRC) and apply for the withholding of information from disclosure. The purpose of this affidavit is to provide the information required by 10 CFR 2.390(b) in support of X-energy's request for proprietary treatment of certain commercial information submitted in Enclosure 1 to X-energy's letter XE-NRC-2022-004 from myself to the NRC which provides responses to Requests for Additional Information on the NRC Assessment of the TRISO-X Pebble Fuel Qualification Methodology for the X-energy Xe-100 Nuclear Reactor.

2. I have knowledge of the criteria used by X-energy in designating information as sensitive, proprietary, confidential, and export-controlled.

3. Pursuant to the provision of paragraph (b)(4) of 10 CFR 2.390, the following is furnished for consideration by the NRC in determining whether the information sought to be withheld from public disclosure should be withheld.

a. The information sought to be withheld from public disclosure in Enclosure 1 is owned by X-energy. This information was prepared with the explicit understanding that the information itself would be treated as proprietary and confidential and has been held in confidence by X-energy.

b. The information sought to be protected in Enclosure 1 is not available to the public.

c. The information contained in Enclosure 1 is of the type that is customarily held in confidence by X-energy, and there is a rational basis for doing so. The information X-energy is requesting to be withheld from public disclosure includes technical information related to the design, analysis and operations associated with our Xe-100 high-temperature, gas-cooled, pebble bed advanced reactor design that directly impact our business development and commercialization efforts. X-energy limits access to this proprietary and confidential information in order to maintain confidentiality.

d. Enclosure 1 contains information about the planned activities of X-energy related to the development of the Xe-100 design bases, forecast design development timeframes, and relate to the commercialization strategy for our Xe-100 advanced reactor. Public disclosure of the information contained in Enclosure 1 would create substantial harm to X-energy because it would reveal valuable technical information regarding X-energy's design development, competitive expectations, assumptions, current position and strategy. Its use by a competitor could substantially improve the competitor's position in the design, manufacture, licensing, construction and operation of a similar competing product.

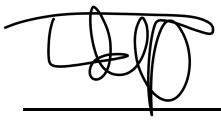
e. Additionally, Enclosure 1 is assessed to contain certain information that is considered Export Controlled Information (ECI) under the provisions of 10 CFR 810. I have personal knowledge of the

criteria used by X-energy to evaluate documents for ECI and affirm that this information should be withheld from public disclosure.

f. The Proprietary Information contained in Enclosure 1 is transmitted to the NRC in confidence and under the provisions of 10 CFR 2.390; it is to be received in confidence by the NRC. The information is properly marked.

I declare under the penalty of perjury that the foregoing is true and correct. Executed on February 28, 2022.

Sincerely,



Travis Chapman
U.S. Licensing Manager, Xe-100 Program
X Energy, LLC

X Energy, LLC
Responses to Requests for Additional Information for X-energy Topical Report,
"TRISO-X Pebble Fuel Qualification Methodology"
(Non-Proprietary)

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NRC Review of: TRISO-X Pebble Fuel Qualification Methodology, Revision 2

NRC RAI Question Number: 1

NRC Question

The fuel design requirements in Section 4 are referred to as "examples of fuel product specification information" and "The fuel and core are to be designed such that there is at least a 50% probability that the FP (sic fission products) release will be less than the 'Maximum Expected' criteria and at least a 95% probability that the release will be less than the 'Design' criteria," initially as part of the iterative process identified in Section 4." Based on the provided information, it is not clear to the NRC staff how the non-final requirements identified in Section 4 could be adequate for establishing a design basis to support licensing, as the X-Energy plant performance envelope is not identified. Please revise the request to better reflect the current state of the design and the state of certainty regarding the performance requirements, or provide additional information to justify how the preliminary information provided can act as the design basis.

X-energy Response

The intent of this report is to communicate the current Xe-100 fuel qualification program and the supporting TRISO fuel experience. Section 4 presents an outline that designers will use to determine radionuclide requirements. The approach includes a determination of as-manufactured fuel quality requirements and top-level design requirements for fuel performance under both normal and accident conditions. However, the complete determination and underlining methodologies are beyond the scope of this report and will be addressed in future topical reports.

The X-Energy preliminary design performance envelope is identified within Figure 25: Assumed Performance Envelope for Qualification of Advanced Gas-cooled Reactor (AGR) Fuel. The preliminary design performance envelope for the Xe-100 core (green star) is comparable to the German envelope shown in the figure and well within the performance envelope for the NGNP that serves as the basis for the AGR Fuel Program.

The request of the NRC staff in Section 7 ["X-energy requests the NRC staff review and approve the following conclusions from this report"] is revised from:

"The fuel design and performance requirements in Section 4 are adequate for establishing an acceptable design basis to support the licensing of the Xe-100 reactor."

to

"The Xe-100 fuel qualification program and associated program elements as outlined in the Executive Summary section of this report are adequate to qualify fuel for the Xe-100."

"Fuel qualification" as used in this report refers to the following program elements:

• Establishment of fuel product, equipment, and feedstock specifications;

• Implementation of a fuel fabrication process capable of consistently and reliably meeting the specifications at the required scale;

• Implementation of statistical QC/QA procedures to demonstrate that the product specifications have been met;

• Irradiation of statistically sufficient quantities of fuel with monitoring of in-pile performance and post irradiation examination to demonstrate that normal operation performance requirements are met; and

• Post-irradiation heating tests (safety testing) of statistically sufficient quantities of irradiated fuel to demonstrate that accident condition performance requirements are met."

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NRC Review of: TRISO-X Pebble Fuel Qualification Methodology, Revision 2

NRC RAI Question Number: 2

NRC Question

The dose criteria and design failure rates provided in Tables 2 and 3 are not themselves characteristics of the TRISO particles. As outlined in Section 5, operation of a reactor for a given set of TRISO particles can result in varying failure rates and mechanisms based on the operating envelope and TRISO particle parameters. These values represent design targets, and the justification for how the actual particles to be used in the XE-100 will meet these targets is unclear. Also, it is not clear how the information provided in Section 4 justifies that the actual TRISO particles in an XE-100 design will remain within acceptable parameters. In order to address this gap, please explain how the designated specification information links to the design requirements (provided at a top level in Table 2), or identify the steps taken in a process (e.g., the additional testing identified in the TR) to link the design requirements to the XE-100 particle specification for the reactor (a "design basis" as stated in the report objective). Alternately, revise the report objective to better reflect the information available at the present time.

X-energy Response

Table 2 in the report represents the top-level radionuclide control requirements for the Xe-100, and Table 3 represents the set of preliminary Xe-100 fuel requirements. The detailed analyses and methodologies that implement the requirements in Table 3 to meet the requirements in Table 2 are illustrated in Figure 5 at a high level. Section 4 presents the approach that X-energy intends to use to implement Table 3 targets as part of future methodology submittals, which are beyond the scope of this report based on X-energy's revised request.

X-energy is revising the request of the NRC staff, as written in the response to RAI #1, to better reflect the information currently available.

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NRC Review of: TRISO-X Pebble Fuel Qualification Methodology, Revision 2

NRC RAI Question Number: 3

NRC Question

The TR requests the NRC review and approve that "Plans established in Section 6 for qualification of the UCO TRISO-coated particles in spheres are generally acceptable," and follows with a list of specifics applicable to this request. These plans provide a link between the tests to be referenced in the code evaluation models and the physical TRISO particles in spherical form planned for use in the X-Energy design. Specifically, the request states **[[ ]]**^{P}, but the TR does not provide sufficient information to address this request. Please provide additional information that qualifies the fuel for an operating range defined by the tests performed or revise the request to reflect the information available in the TR.

X-energy Response

[[

]]^{P} The AGR compact irradiation campaigns established a performance envelope for UCO TRISO in compacts. The envelope is bounded by the parameters: burn-up, power density, fuel element packing fraction, time-averaged temperature, and fast fluence. Specifically, the UCO TRISO from irradiated AGR-1 compacts, after burn-up in FIMA to ~20%, exhibited two failed particles after 300 hours in a safety heat-up test to 1800°C. Accordingly, the Xe-100 design, code evaluations, and models are based upon this level of failed particles and associated fission product release, at the same temperature and time at temperature. In other words, in an accident scenario, if the temperature of the Xe-100 remains below 1800°C for 300 hours then no failed particles are expected. Note that this AGR-1 data used to support the Xe-100 design and safety analysis report is based on UCO TRISO in cylindrical compact form, made to NQA-1 approved manufacturing processes for kernels, TRISO, and compacts. Because no spherical fuel elements were produced under the AGR program, an NQA-1 approved process for producing pebbles does not exist. [[

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NRC Review of: TRISO-X Pebble Fuel Qualification Methodology, Revision 2

NRC RAI Question Number: 4

NRC Question

No information is provided regarding qualification of parameters aside from burnup, fluence, and temperature.

A) Please discuss the impact of transient conditions (e.g., heat up rate) on the fuel and describe how X-Energy plans to address this (testing not cited here, other literature, etc.).

B) Please provide any other parameters not discussed in this TR (e.g., particle power) that will be addressed in other licensing submittals that impact the fuel qualification.

C) Please provide a discussion of parameters not related to thermal or nuclear parameters that may impact fuel qualification (e.g., mechanical effects on the pebbles) as applicable, or provide a statement that these effects are not within the scope of this report.

X-energy Response

A) X-energy is currently evaluating reactivity insertion accidents and based on preliminary results doesn't expect to reach an enthalpy deposition limit. X-energy plans to verify energy deposition rates against transient tests results currently available as represented in Table 1. These tests subjected UO_2 fuel to a range of energy depositions.

Table 1: Historical transient testing for TRISO particles [1]

Reactor	Fuel Type	Type	Energy Deposition (J/g-UO2)	Pulse Width (ms)	Fuel Failure
NSRR (Fukeda)	UO2	Element and loose particle	500 - 2300	5	> 1400 J/g
NSRR (Umeda)	UO2	Loose particle	500 – 1700	5	> 1400 J/g
HYDRA	UO2	Element and loose particle	100 – 1700	1 – 2	> 1300 J/g
IGR	UO2	Element	> 10000	700 – 30000	Matrix Failure

The work performed at ORNL by Schappel, et al, [2] found that fuel melt is predicted by BISON at about the same energy deposition as the onset of SiC fracture. However, the authors expect that the onset of fracture for the SiC could occur before fuel melting if wider pulses were used. Schappel, et al, [2] also performed a review of HTGR Reactivity-Initiated Accident (RIA) events available in literature. The RIA data review showed that the kernel energy deposition in pebble-bed HTGRs is less than the lowest fuel kernel energy deposition (~ 500 J/g UO_2) in the Nuclear Safety Research Reactor (NSRR) experiments.

X-energy expects that existing AGR test data provides coverage of both fast and slow temperature ramping transients for the Xe-100 design. The AGR program completed two transient tests to a peak temperature of 1700°C [3] [4]. Each test involved 3 fuel compacts. These tests were based on previous tests done in Germany on Arbeitsgemeinschaft Versuchsreaktor (AVR) spheres. The temperature profile during the tests was based on the predicted peak core temperature trajectory during a depressurized loss of forced cooling accident in the HTR MODUL reactor design, but with the entire curve shifted approximately 100°C and achieved a peak temperature of 1700°C instead of the 1600°C. Excluding the ramp rates at lower temperatures, the highest ramp rate of the tests was approximately 120°C/h. The results demonstrated that there was no increase in particle failure rates as a result of the varying temperature profile.

X-energy plans to submit future topical reports that will address transient impacts on fuel in detail.

References

1. Nicholas R. Brown, "A review of in-pile fuel safety tests of TRISO fuel forms and future testing opportunities in non-HTGR applications", Journal of Nuclear Materials 534 (2020), https://doi.org/10.1016/j.jnucmat.2020.152139
2. D. Schappel, N.R. Brown, K.A. Terrani, "Modeling reactivity insertion experiments of TRISO particles in NSRR using BISON", Journal of Nuclear Materials 530 (2020), https://doi.org/10.1016/j.jnucmat.2019.151965
3. John D. Stempien, et al., "High-temperature safety testing of irradiated AGR-1 TRISO fuel," Paper 18595, Proceedings of the 8th International Topical Meeting on High Temperature Reactor Technology (HTR2016), November 6-10, 2016, Las Vegas, Nevada, USA
4. John D. Hunn et al., "Transient Temperature Safety Testing of AGR-2 UCO Compacts 5-1-1, 5-1-2, and 5-3-1." ORNL/TM-2019/1292, Oak Ridge National Laboratory, 2019

B) Figure 25 identifies preliminary design performance envelope and associated parameters of interest. Additional parameters of interest may appear in future submittals. Power per particle may appear in future submittals but is derived from power density from Figure 25. X-energy also plans to submit maximum accident temperature versus time at temperature and associated ramp rates as figures of merit for accident analysis. Additional figures of merit that may impact fuel qualification identified in future topical reports will be presented to the staff for evaluation.

C) X-energy plans to provide discussion on this topic in future submittals. Parameters not related to thermal or nuclear parameters are outside of the scope of this report.

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NRC Review of: TRISO-X Pebble Fuel Qualification Methodology, Revision 2

NRC RAI Question Number: 5

NRC Question

A) Specifically, is it X-Energy's intent to perform this process for **[[ ]]^{P},** or is the figure providing an "example" of what might be done? If it is an example, please provide additional information for how test results and associated acceptance criteria will be designated as successful or representative for use in qualifying the fuel performance (i.e., which isotopes will be measured, how will particles be designated as failed). Additionally, please provide any information regarding whether AGR 5/6/7 data will be used when it becomes available (or if the position is that the proposed testing will supersede those results, provide a statement to that effect).

B) [[

]^{P}

X-energy Response

Figure 38 of the Fuels Qualification Methodology Report shows a simplified flowchart of the Xe-100 TRISO Post Irradiation Examination (PIE) Protocol.

A) X-energy intends to perform this process for [[ ]]^{P} material exactly as shown in the Figure 38 flowchart.

The AGR 5/6/7 test compacts differ from the Xe-100 fuel spheres. The AGR program was focused on qualifying UCO TRISO-coated particles in cylindrical fuel compacts that are characteristic of prismatic fuel elements. The process conditions for making fuel spheres are different from those associated with making fuel compacts. AGR compacts were pressed to nominally 15 MPa at elevated temperatures, whereas spherical pebbles are cold pressed at about 300 MPa. It is worth noting that the packing fraction, or volume of the fuel element occupied by TRISO particles, is higher in a compact than in a pebble, as AGR compacts were 37% packing fraction [[ ]]$^{P, E}$. However, regardless of packing fraction, the key in manufacturing a fuel element, of any geometry, is to not damage the layers of the TRISO particle. [[

]]^{P}

[[

]]$^{P, E}$

Regarding AGR-5/6/7 data, X-energy will follow the PIE results but have no plans, at this time, to include any data. As previously noted, the AGR-5/6/7 compacts did not meet manufacturing specifications and are not representative of Xe-100 fuel.

B) [[

]]^{P}