Xe-100 Spent Fuel Management Licensing Approach White Paper

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Agenda & Objectives

Agenda:

Open Portion:

- Part 50 vs. Part 72 Applicability to Xe-100 Spent Fuel Management
- Applicable Regulations & Review Guidance
- Post-Operating License Regulatory Framework
- Overview of Negotiations with DOE
- Discuss X-energy's Compliance Approach for 10 CFR 50.68

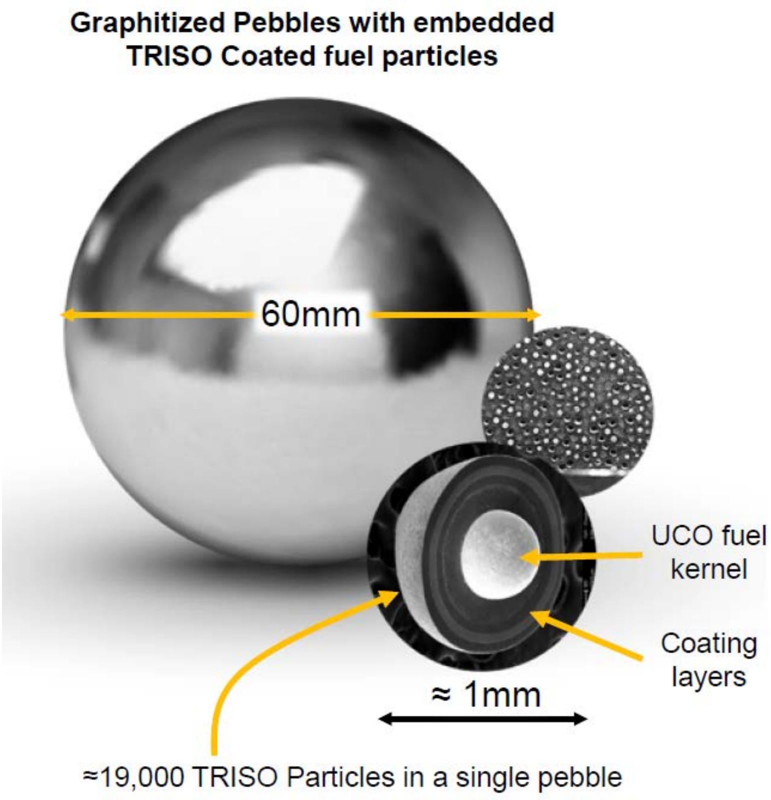
Closed Portion:

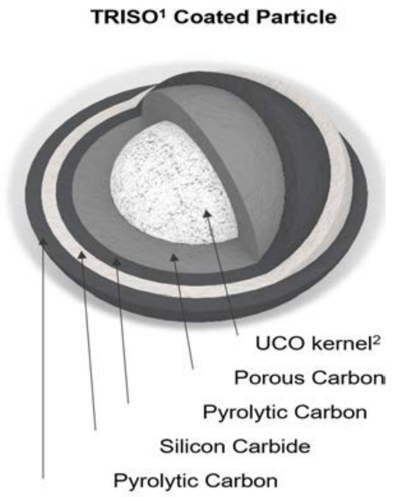
- Overview of Xe-100 Site Layout, Fuel Design, and Spent Fuel Storage System (SFSS)
- Spent Fuel Management Approach – Technical Implementation

Objectives:

- Receive feedback on the scope of this proposed preapplication engagement (white paper)
- Receive feedback on the licensing approach to meeting 10 CFR 50.34 technical requirements with NUREG-2215 review guidance
- Achieve alignment on 10 CFR 50.68 approach
- Provide NRC staff updated design information on the Xe-100 spent fuel storage system and other fuel-related technical development

Xe-100 Fuel Design – TRISO-Coated Particles & Fuel Pebble



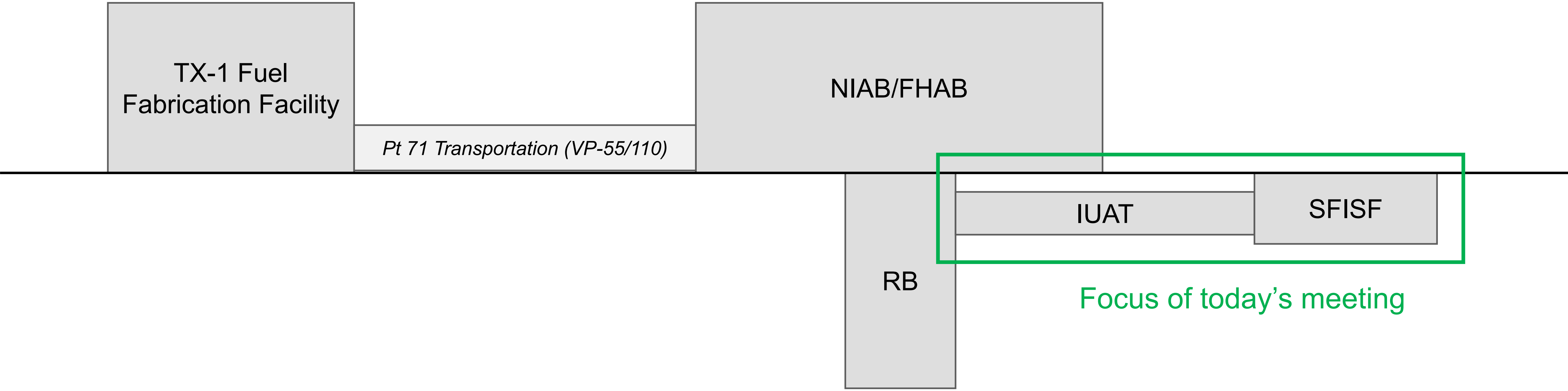


1) TRi-structural ISOtropic particle
2) Uranium OxyCarbide

- **TRISO / HALEU UCO**
  - HALEU UCO kernel coated with layers of carbon, pyrolytic carbon & silicon carbide to form a TRISO particle

- **TRISO-coated fuel pebbles**
  - TRISO-coated fuel provides robust efficient (99.999%) containment of radionuclides within the TRISO particles, based on extensive development and testing through the DOE's Advanced Gas Reactor (AGR) program

New & Spent Fuel Management – Functional Arrangement



Applicability of Part 50 Vs. Part 72 for Spent Fuel Management

- The SFSS offloads spent fuel spheres to canisters that are transferred directly to storage locations within the SFISF. The SFISF is integrated with the Xe-100 reactor plant design.
- Each project will apply for a 40-year Operating License (OL) for the units in the plant, with one 20-year license renewal (Part 54) incorporated into the Xe-100 design
- The SFISF is designed to safely store for a minimum of 80 years all spent fuel generated over a 60-year plant design life (20-year period of extended operation (PEO))
- Although the SFISF resembles a Part 72 Independent Spent Fuel Storage Facility (ISFSI) in many respects, it does not initially qualify for a Part 72 General or Specific License
  - Part 72 requires power reactor spent fuel to be aged for at least one year. Since the SFSS loads spent fuel canisters directly into each SFISF with less than one year of decay, Part 50 is selected as the more applicable regulation. Licensure of the SFISF will be included in the plant's Part 50 permit/license applications.
- An initial Part 72 application is for 40 years, with one Part 72 license renewal not to exceed 40 years
- Submitting a single Part 54 License Renewal Application (LRA) versus separate Part 54 and Part 72 LRA prior to PEO would reduce regulatory burden for both the NRC and the Licensee

Applicable Regulations & Review Guidance

10 CFR 50.34 is an applicable regulation for licensing the Xe-100 SFSS:

- 10 CFR 50.34(a)(3)(i) and (ii) inform the Xe-100 application content at the Preliminary Safety Analysis Report (PSAR) stage:
  - Identification of Principal Design Criteria (PDC) as developed from RG 1.232 and RG 1.233.
  - Description of the design bases relative to the PDCs
  - Because NUREG-0800 provides limited Standard Review Plan (SRP) guidance that is applicable to the Xe-100 SFSS, the similarity of the SFISF to an ISFSI suggests the use of NUREG-2215 SRP guidance as a general guideline to inform the review
- 10 CFR 50.34(b)(2) and (10) inform the Xe-100 application content at the Final Safety Analysis Report (FSAR) stage
- NUREG-2215 provides a general approach to reviewing spent fuel management activities that is applicable to the Xe-100 design and concept of operations

Post-Operating License Regulatory Framework

- Each unit will hold a 40-year Operating License, with a design life for non-replaceable components accommodating a 20-year Part 54 license renewal
- The SFISF and the spent fuel canisters are designed to maintain function for a minimum of an 80-year period from initial issuance of the OL
- The design considers when the OL expires after 60 years, and SFM must continue for the next 20 years. X-energy proposes the following:
  - Prior to the expiration of the OL, each unit's Xe-100 reactor will be defueled and all canisters loaded into its associated SFISF
  - After the expiration of the OL, Part 54 aging management will continue to apply to the SFISF and building contents until the spent fuel is transferred to the DOE
  - Post-OL, SFM will be conducted in accordance with 10 CFR 50.51(b) which authorizes continued storage, control, and maintenance of spent fuel in a safe condition
  - During the 20-year decommissioning period, the Licensee will retain custody of special nuclear material under its Part 70 license until spent fuel transfer to DOE

DOE Negotiations on Spent Fuel Transfer

- The Nuclear Waste Policy Act (NWPA) of 1982 established a national program for the safe, permanent disposal of highly radioactive wastes. Specifically, Congress assigned responsibility to DOE to site, construct, operate, and close a repository for the disposal of spent nuclear fuel and high-level radioactive waste.
- The SFISF design allows onsite storage of all spent fuel generated during a 60-year plant design life and for up to 20 years following cessation of plant operation
- X-energy has started negotiations with DOE on a standard contract for receipt of Xe-100 spent fuel
- Alternately, the spent fuel canisters could be transported to a Part 72 Consolidated Interim Storage Facility owned & managed by another licensee

Compliance Strategy for 10 CFR 50.68 (Option 1)

The requirements of 10 CFR 50.68 will be applicable in a Part 50 application. The regulation allows two options for compliance. Option 1 is discussed below:

- 10 CFR 50.68(a) – Compliance with 10 CFR 70.24. This is met by the following requirements of 10 CFR 70.24:
  - 10 CFR 70.24(a) – If this path were chosen, Xe-100 TRISO fuel would be required to meet the special nuclear material criteria of 10 CFR 70.24(a). Therefore, a criticality monitor would be required meeting the requirements of paragraph (a)(1) or (a)(2), unless the requirements of 10 CFR 50.68(b) are met.
  - 10 CFR 70.24(b) - 10 CFR 70.24(b) is not applicable to the Xe-100 reactor per 10 CFR 70.24(c).
  - 10 CFR 70.24(c) - The Xe-100 reactor is not a critical assembly reactor. Therefore, paragraph (b) is not applicable
  - 10 CFR 70.24(d) - X-energy does not intend to change its compliance strategy for criticality monitoring once it is established
- X-energy does not intend to pursue a compliance strategy based on 10 CFR 50.68(a)

Compliance Strategy for 10 CFR 50.68 (Option 2)

The second option for 10 CFR 50.68 compliance is a procedural and analytical alternative to the Part 70.24 criticality monitoring instrumentation:

- Per 10 CFR 50.68(b)(1): *Plant procedures shall prohibit the handling and storage at any one time of more fuel assemblies than have been determined to be safely subcritical under the most adverse moderation conditions feasible by unborated water*

  The Xe-100 reactor would require an Exemption from this requirement since "fuel assemblies" are not applicable to the design. The design will be analyzed to ensure fuel handling in the most adverse moderation conditions feasible is evaluated and determined to be safely subcritical.

- Per 10 CFR 50.68(b)(2): *The estimated ratio of neutron production to neutron absorption and leakage (k-effective) of the fresh fuel in the fresh fuel storage racks shall be calculated assuming the racks are loaded with fuel of the maximum fuel assembly reactivity and flooded with unborated water and must not exceed 0.95, at a 95 percent probability, 95 percent confidence level. This evaluation need not be performed if administrative controls and/or design features prevent such flooding or if fresh fuel storage racks are not used.*

  The Xe-100 reactor would require an Exemption from this requirement since "fresh fuel storage racks" and "fuel assembly" are not applicable to TRISO fuel. Analogous conditions for fresh fuel storage will be evaluated against the same acceptance criteria for k-effective.

Compliance Strategy for 10 CFR 50.68 (Option 2)

- Per 10 CFR 50.68(b)(3): *If optimum moderation of fresh fuel in the fresh fuel storage racks occurs when the racks are assumed to be loaded with fuel of the maximum fuel assembly reactivity and filled with low-density hydrogenous fluid, the k-effective corresponding to this optimum moderation must not exceed 0.98, at a 95 percent probability, 95 percent confidence level. This evaluation need not be performed if administrative controls and/or design features prevent such moderation or if fresh fuel storage racks are not used.*

  The Xe-100 design precludes presence of water moderation or low-density hydrogenous fluid (i.e., borated or unborated water) where the fresh fuel is stored onsite, therefore this requirement is not applicable, and no evaluation will be performed.

- Per 10 CFR 50.68(b)(4): *If no credit for soluble boron is taken, the k-effective of the spent fuel storage racks loaded with fuel of the maximum fuel assembly reactivity must not exceed 0.95, at a 95 percent probability, 95 percent confidence level, if flooded with unborated water. If credit is taken for soluble boron, the k-effective of the spent fuel storage racks loaded with fuel of the maximum fuel assembly reactivity must not exceed 0.95, at a 95 percent probability, 95 percent confidence level, if flooded with borated water, and the k-effective must remain below 1.0 (subcritical), at a 95 percent probability, 95 percent confidence level, if flooded with unborated water.*

  The Xe-100 reactor would require an Exemption from this requirement since "spent fuel storage racks" and "fuel assemblies" and soluble boron are not applicable to the Xe-100 reactor design nor pebble fuel, however the intention codified in the regulation's term "maximum fuel assembly reactivity" will be met by the Xe-100 reactor design.

- Per 10 CFR 50.68(b)(5): *The quantity of SNM, other than nuclear fuel stored onsite, is less than the quantity necessary for a critical mass*

  The Xe-100 reactor design will comply with this requirement.

Compliance Strategy for 10 CFR 50.68 (Option 2)

- Per 10 CFR 50.68(b)(6): *Radiation monitors are provided in storage and associated handling areas when fuel is present to detect excessive radiation levels and to initiate appropriate safety actions.*

  The Xe-100 reactor design will comply with this requirement.

- Per 10 CFR 50.68(b)(7): *The maximum nominal U-235 enrichment of the fresh fuel assemblies is limited to five (5.0) percent by weight*

  The Xe-100 reactor requires an Exemption from this requirement since the TRISO equilibrium fuel is enriched to more than 5.0 wt.% U-235 and is not stored in fuel assemblies. SECY-21-0109 was approved by NRC, which directs a rulemaking for 10 CFR 50.68(b) for HALEU fuel by June 30, 2026. Although this is applicable to LWR fuel, this rulemaking could limit the scope of the necessary Exemption to “fuel assemblies” subject to final enrichment levels included in the rule.

- Per 10 CFR 50.68(b)(8): *The FSAR is amended no later than the next update which § 50.71(e) of this part requires, indicating that the licensee has chosen to comply with § 50.68(b)*

  X-energy will comply with this requirement after receipt of the OL.

Conclusion

The PSAR does not require a specific determination of how compliance with 10 CFR 50.68 will be achieved given that the design is preliminary. Notwithstanding, X-energy intends to pursue a compliance strategy of meeting 10 CFR 50.68(b) with the Exemptions described above based on Xe-100 SFSS design considerations. These Exemption requests and bases will be submitted during the FSAR phase of the NRC’s Part 50 OL review.

Conclusion / Next Steps

X-energy will document in the Spent Fuel Licensing Approach and Regulatory Analysis White Paper the following information:

- An overview of the proposed Xe-100 SFSS
- Discussion that 10 CFR 50.34 is applicable to spent fuel management, rather than 10 CFR 72
- Discussion that NUREG-2215 should constitute the principal review guidance for the Xe-100 SFSS, rather than NUREG-0800
- Discussion that 10 CFR 50.51(b) will be applicable for spent fuel management until the spent fuel is transferred to the DOE
- X-energy has begun negotiations with the DOE for acceptance of spent fuel under a standard contract
- 10 CFR 50.68(b) is the compliance strategy for criticality monitoring, with certain expected Exemption requests

Closed Portion

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Proposed Plant Site Layout

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- This graphic shows the proposed site layout for a 4-unit Xe-100 plant
- Everything necessary to operate Unit 1 (shown in red outline) will be installed at the same time, including common plant services, equipment, and buildings. Construction of Unit 1 includes a single SFISF for storage of spent fuel
- Subsequent units will be installed and connected to common plant services, equipment, and buildings. This includes a shared Inter-Unit Access Tunnel (IUAT) connecting all Units to all SFISFs

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Overview of the Xe-100 Fuel Cycle

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- The Xe-100 is a graphite moderated pebble bed, helium gas-cooled, high temperature reactor. Each reactor is planned to generate [[ ]]P and approximately [[ ]]P.
- The fuel-free pebble is a spherical graphite element without uranium used during the start-up process
- The start-up fuel is a spherical fuel element that utilizes the tristructural isotropic (TRISO) particle nuclear fuel design, with low enriched uranium enriched to [[ ]]P in the form of a uranium oxide-carbide mixture
- The equilibrium fuel is a spherical fuel element that utilizes the TRISO particle nuclear fuel design, with high-assay low enriched uranium (HALEU) enriched to [[ ]]P in the form of a [[ ]]P
- There are approximately [[ ]]P fuel spheres in the core at any given time, with up to [[ ]]P fuel spheres per day circulated through the Fuel Handling System (FHS). Fuel spheres travel through the core on average up to [[ ]]P times over [[ ]]P days before being discharged.
- At full power, [[ ]]P fresh fuel spheres are added to the core daily and the same number of burned up (spent) fuel spheres are removed
- The FHS extracts spent fuel spheres and loads them into spent fuel canisters (SFC)

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Xe-100 SFSS Top-Level Design Requirements

The Spent Fuel Storage System is comprised of the SFISF (a structure), IUAT (structure), FHS (for spent fuel loading), Spent Fuel Canisters (SFCs), and Spent Fuel Canister Carts

- Each SFC is loaded with up to [[ ]]P spent fuel spheres per full power day
- Each SFC, which will be uniquely identified to support inventory tracking, is designed to store up to [[ ]]P spheres
- At all times and conditions, a SFC remains sub-critical (k_{eff}<0.95)
- Each SFC is cooled by natural convection
- The SFSS is capable of filling [[ ]]P SFCs per reactor per full power year
- The SFISF provides sufficient storage capacity for all fuel spheres generated during an assumed 60-year plant operational life
- The SFISF is designed for an 80-year service life

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Spent Fuel Canister (SFC)

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Overview of the Xe-100 SFSS Design

All movement of SFCs between the RB, FHAB, and SFISF occurs below-grade via the Inter-Unit Access Tunnel (IUAT).

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- The SFC lid is welded onto the canister and the canister is decontaminated prior to storage in an SFISF.
- IUAT design (subgrade) minimizes dose rates above the IUAT during canister movement.

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Overview of the Xe-100 Spent Fuel Intermediate Storage Facility

- The SFISF has dimensions of approximately [[ ]]P. Walls and roof are a minimum of [[ ]]P thick reinforced concrete.
- [[ ]]P SFISFs are required to support a 4-unit site for a 60-year design life.
- Each SFISF includes [[ ]]P canister storage racks [[ ]]P fabricated of structural steel members
- [[ ]]P
- [[ ]]P
- [[ ]]P

[[ ]]P

Overview of SFISF Cooling

- The SFISF ensures passive cooling of SFCs through natural air convection
- A conservative fuel sphere temperature limit of [[ ]]P has been selected as an evaluation Figure of Merit (FOM) to minimize the potential for graphite oxidation based on past precedent
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Radioactive Spent Fuel Handling

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- This allows plant personnel to have minimal exposure to the SFSS and conform with ALARA principles

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Spent Fuel Canister Cart System Architecture

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