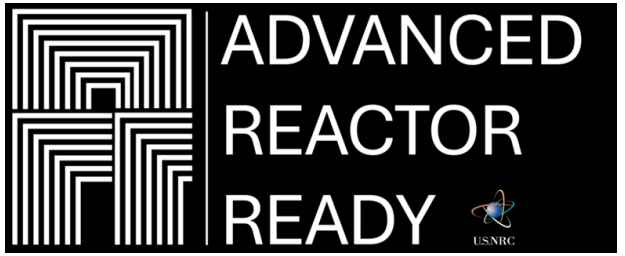
NRC Staff Review of Topical Report (TR) 000632 "Xe-100 Licensing Topical Report Mechanistic Source Term Approach" (MST)

ACRS Full Committee Meeting
July 9, 2025



https://www.nrc.gov/reactors/new-reactors/advanced.html

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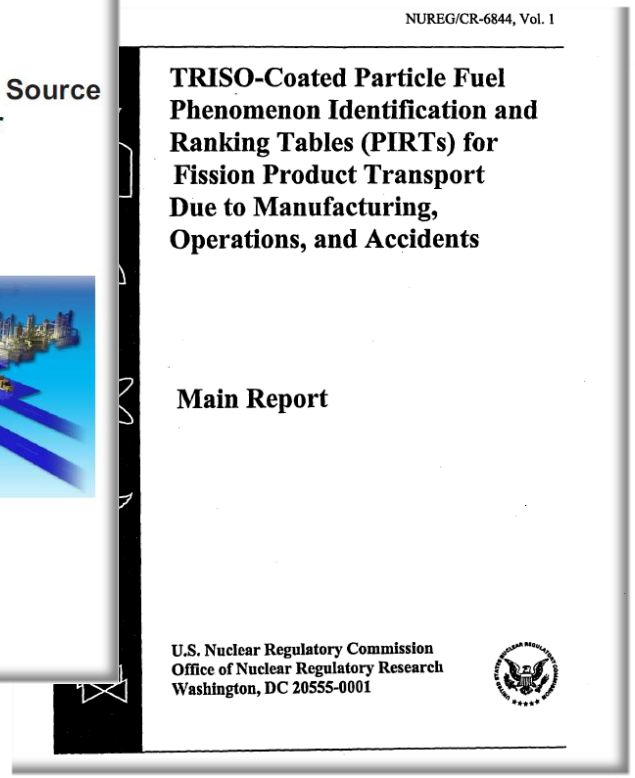
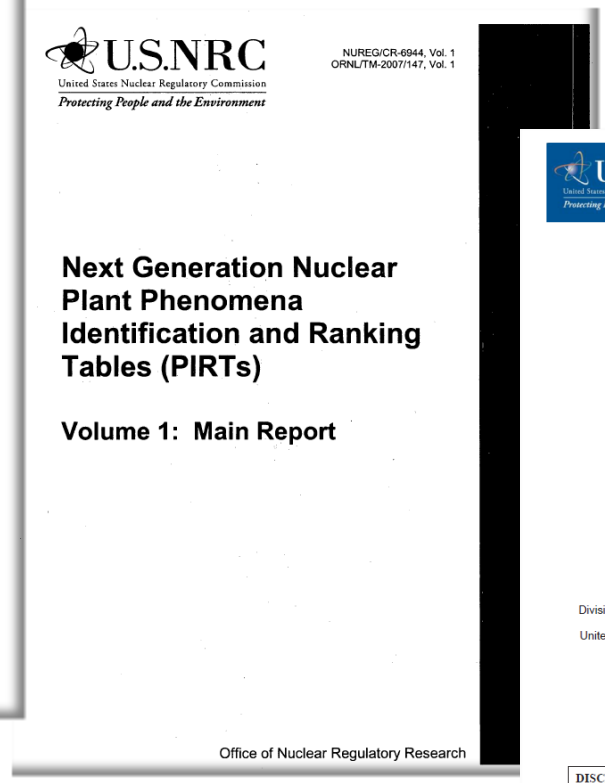
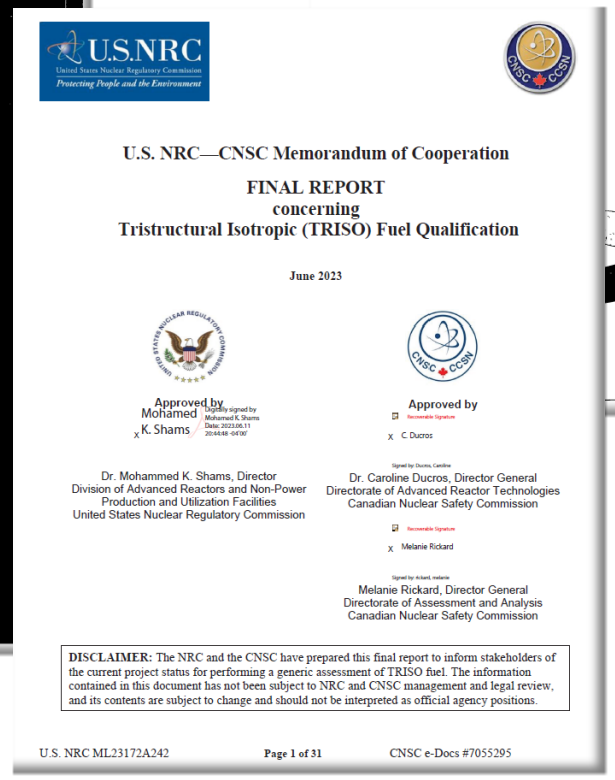
Background

- MST TR originally submitted on May 10, 2024 (ML24131A146) with updated submittal on March 14, 2025 (ML25073A093)
  - Updated submittal includes updates identified during regulatory audit
    - Updates to MST TR sections 1.5 and 7.1 clarify that applicability is limited to preliminary analyses
    - Correction of typos
    - Updates to Appendix H showing MST model interfaces

Background







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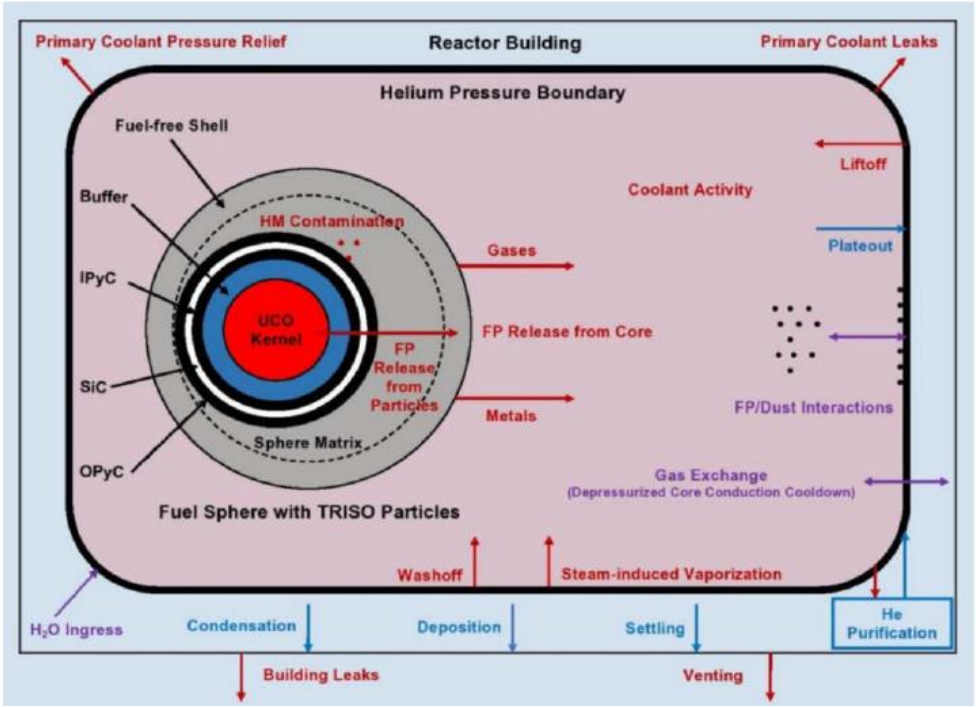
Regulatory Basis

- Title 10 of the *Code of Federal Regulations* (10 CFR) 50.34(a)(1)(ii)(D) requires, in part, that an applicant for a construction permit (CP) perform an evaluation and analysis of a **postulated fission product release** to evaluate the offsite radiological consequences.
- Under 10 CFR 50.34(a)(4) an applicant for a CP must perform a **preliminary analysis and evaluation of the design and performance of structures, systems, and components** with the objective of assessing the risk to public health and safety resulting from the operation of the facility and including the determination of margin of safety during normal operations and transient conditions anticipated during the life of the facility.
  - Staff identified relevant Principal Design Criteria (PDC): Xe-100 PDC 10, RFDC 16, PDC 19
- Under 10 CFR 50.34(a)(8) an applicant for a CP must identify the systems, structures or components of the facility, if any, which require research and development to confirm the adequacy of their design and describe the **research program that will be conducted to resolve any safety questions associated with such systems, structures, or components**. Such research and development may include obtaining sufficient **data regarding the safety features of the design to assess the analytical tools** used for safety analysis in accordance with 10 CFR 50.43(e)(1)(iii).

Scope of NRC Staff Review

- MST TR section 4.2 describes that MST models, implemented in the XSTERM code, are used to calculate dose consequences for licensing basis events, including the deterministic evaluation of design basis accidents
- NRC staff reviewed MST modeling approach to address radionuclide transport phenomena to support preliminary analysis of the Xe-100
- Review is limited to and focused on high-level physical phenomena of interest and whether the analysis approach and methods can reasonably support future licensing actions
  - Design is preliminary
  - Development and assessment of methods are in progress or planned
  - Evaluation of models within XSTERM for acceptability will be conducted during the review of an application that relies on the results of XSTERM evaluations

Barriers to Radionuclide Release



- Fuel
  - Fuel particle kernel (Uranium Oxycarbide (UCO)) within the TRISO fuel particles
  - Silicon Carbide and Pyrolytic Carbon coatings applied to the fuel kernel
  - Fuel matrix and fuel free zone of the fuel pebble
- Helium Pressure Boundary
- Reactor Building (Not credited)

XSTERM Models

- MST TR describes nine models in XSTERM:
  - Thermodynamics Calculation Model (THM)
    - NRC staff identifies this model to be of high importance because radionuclide release is expected to be diffusion dominant (temperature-dependent).
    - Use of THM for analyses supporting a Xe-100 licensing application requires justification by the applicant.
  - Point Kinetics Core Simulation Model (KSIM)
    - The description of point kinetics appears to be different than standard point kinetics approaches (i.e., 0D, single eigenvalue, lack diffusion coupling). Use of KSIM for analyses supporting a Xe-100 CP application requires justification by the applicant.
  - Tritium Production and Transport Model (TRITM)
    - MST TR section 5.1.8 clarifies that this model is under development.

XSTERM Models

- MST TR describes nine models in XSTERM (cont):
  - TRISO Particle Failure Probability Model (FPM)
  - Solids Product Transport Calculations Model (SOLM)
  - Steady-State Gaseous Fission Products Transport Calculations Model (GASM)
  - Dust Production Rate Calculations Model (DUSTM)
  - Helium Pressure Boundary Model (HPBM)
  - Core Corrosion Model (CORRM)
- NRC staff determined that FPM, SOLM, GASM, DUSTM, HPBM, and CORRM address phenomena needed to predict MST to support preliminary analysis:
  - Models rely on previous modeling and operational experience from gas-cooled reactors such as Arbeitsgemeinschaft Versuchs Reaktor (AVR)
  - Based on the NRC staff's experience with light water reactor (LWR) and non-LWR source term analysis, the NRC staff did not identify significant gaps in the MST models.
  - MST TR section 4.2 states that the source term modeling described may be revised
    - NRC staff did not perform a detailed technical review for the models described in MST TR
    - NRC make no conclusions regarding the acceptability of these models

Assessment Plans (Verification and Validation (V&V))

- MST TR section 6 states that:
  1. V&V effort is underway to ensure that XSTERM is qualified to support final safety analyses
  2. Validation plans are developed to cover high and medium ranked phenomena that are identified through a Phenomena Identification and Ranking Table (PIRT) process
  3. The phenomena modeled by XSTERM were extracted from an earlier version of the PIRT
- NRC staff determined that the assessment process is acceptable because the identification of code assessment requirements through the PIRT process is an established approach (see RG 1.203)
- NRC staff are unable to assess the adequacy of the V&V plan:
  - Validation plan is not based on the latest PIRT information
  - MST TR does not contain information describing the knowledge level of the phenomena identified in the PIRT
  - The plan is preliminary and subject to change

Conclusions

- The NRC staff concludes that X-energy's TR 000632, "Xe-100 Licensing Topical Report Mechanistic Source Term Approach," Revision 3, provides a reasonable plan for the development of the MST methodology.
  - The FPM, SOLM, GASM, DUSTM, HPBM, CORRM models in XSTERM appear to cover the phenomena needed to predict the MST to support the preliminary analysis and evaluation of the Xe-100 design
  - The TR describes an acceptable approach to V&V
- NRC staff make no conclusions regarding the acceptability of the models in XSTERM for the MST analyses of the Xe-100 because:
  - Models within XSTERM are still under development
  - A detailed technical review of the individual models was not completed
  - Details regarding key phenomena identification and associated knowledge levels are not provided in MST TR
  - The models and associated validation plans are preliminary and subject to change
- The NRC staff expects that a detailed technical review of XSTERM model applicability to the Xe-100 reactor will be addressed as part of the review of a licensing application that references MST TR.

Acronyms

AVR	Arbeitsgemeinschaft Versuchs Reaktor
CORRM	Core Corrosion Model
CP	Construction Permit
DUSTM	Dust Production Rate Calculations Model
FPM	Failure Probability Model
GASM	Steady-State Gaseous Fission Products Transport Calculations Model
HPBM	Helium Pressure Boundary Model
KSIM	Point Kinetics Core Simulation Model
LWR	Light Water Reactor
MST	Mechanistic Source Term
PDC	Principal Design Criteria
PIRT	Phenomena Identification and Ranking Table
SOLM	Solids Product Transport Calculations Model
THM	Thermodynamics Calculation Model
TR	Topical Report
TRISO	Triple Coated Isotropic Particle
TRITM	Tritium Production and Transport Model
UCO	Uranium Oxycarbide
V&V	Verification and Validation