August 20, 2024

Discussion related to X-energy's Topical Reports; GOTHIC and Flownex Analysis Codes Qualification, Reactor Core Design Methods and Analysis, Transient and Safety Analysis Methodology, and Mechanistic Source Term Approach

Preliminary questions on the four related Xe-100 topical reports

Crosscutting items across TRs

1. The topical reports appear to represent the early phase of the overall implementation of the safety analyses (i.e., licensing basis event (LBE) analyses under the Licensing Modernization Project (LMP)) required by the applicable regulations under Title 10 of the *Code of Federal Regulations* (10 CFR) Parts 50 and 52). For example,

    - The Transient and Safety Analysis Methodology topical report, in Section 2.5, states that "X-energy believes that while the Xe-100 design is not finalized, it is at a point to support X-energy's request for the US NRC to review and approve the proposed approach to performing transient and safety analyses for the Xe-100 reactor."
    - The Mechanistic Source Term Approach topical report states that "X-energy is requesting the NRC review and approval of the MST models described in Section 4.1, Section 5, and Appendices A through H of this LTR as an appropriate means to evaluate radionuclide transport phenomena and estimate mechanistic source terms."
    - The GOTHIC and Flownex Analysis Codes Qualification topical report states, in the Synopsis section, that "As a starting point, this report provides the overall framework and approach taken by X-energy to develop specific code methodologies, models, and Verification and Validation (V&V)."

    The topical reports refer to the preliminary nature of the Xe-100 design, state that additional work needed as part of the LMP implementation, and generally make it apparent to staff that 1) what is provided in the topical reports reflects the early-phase approach, methodology, or means and 2) X-energy intends, in the future, to provide additional information for review and approval in revised topical reports or as a part of a future licensing application.

    With this context, it is not clear what X-energy intends that staff review and approve, nor what X-energy would interpret that approval to mean or allow. Additional clarity and consistency will help the NRC staff regarding what corresponding findings to make, limitations and conditions to identify, and conclusions to reach in the safety evaluations.

2. The scope of the topical reports regarding LBEs under the LMP methodology is not clear or consistent. X-energy should explain the scope of LBEs for the topical reports and make needed revisions to the topical reports. That will ensure consistency with the NRC staff's review of the TRs.

   For example, Sections 1.5 and 13, respectively, of the Transient and Safety Analysis Methodology topical report state that "X-energy is requesting NRC review and approval of the evaluation model presented in this LTR for analysis of design basis accidents, …" Section 10, "Xe-100 LBE Evaluation Model," states that "The Xe-100 LBE evaluation model is the calculational framework for evaluating the behavior of the reactor system during a postulated transient. There is one Evaluation Model for modeling all LBEs (AOOs, DBEs, BDBEs, and DBAs) of the Xe-100, comprising several calculational devices: Flownex, XSTERM, and GOTHIC computer codes." Section 13.1, "Conclusions," states that "This document describes the evaluation model developed by X-energy to analyze LBEs for the Xe-100 reactor developed in accordance with RG 1.203."

   The Xe-100 TR, "GOTHIC and Flownex Analysis Codes Qualification," which presents the acceptability of the codes to model the LBEs in support of the X-energy safety analysis, states that "Xe-100 Licensing Topical Report, "Transient and Safety Analysis Methodologies"[2], describes the methods and models used to determine offsite dose and control room dose resulting from licensing basis events (LBEs) identified in the Probabilistic Risk Assessment (PRA) and related safety analyses," indicating these TR's scope covers LBEs, not just DBAs. Note also that the Atmospheric Dispersion and Dose Calculation Methodology TR, cover LBEs broadly to follow the LMP process.

3. The use of terminologies related to the events or event sequences being analyzed in the topical reports should be clear and consistent with the LMP terminologies to the extent practical. X-energy should make needed revisions to the topical reports.

   For example, the topical reports use expressions such as transient, postulated accident, postulated transient, accident, accident sequence, accident condition, and event. Since X-energy is following the LMP, the consistent use of the LMP terminologies (such as licensing basis event, anticipated operational occurrence, design basis event, beyond design basis event, and design basis accident in addition to initiating event used in the PRA development) should be used to avoid misinterpretation or confusion. For cases where certain non-LMP expressions need to be used, it should be made clear what they are in relation to the LMP terminologies or defined explicitly. Another example is the use of "initiating events" rather than "LBEs" in TSA TR Section 11.

4. The reactor core design methods topical report, section 3.2.3, states that "the Xe-100 reactor core design only uses the 2-dimensional (RZ) model." However, the Transient and Safety Analysis Methodology topical report, Section 5.2, states "…performing the multi-group neutron diffusion calculation in two or three dimensions…" and Section 10.1 indicates that VSOP is used to calculate steady-state 3-D neutronic flux, power, and temperature distributions to serve in setting up initial conditions for safety analyses. Clarify when VSOP calculations are performed in 2-D vs. 3-D in the evaluation model.

Mechanistic Source Term Approach TR

5. Thermodynamics Calculation Model (THM)
   a. THM is a heat transfer model that uses flow rates from VSOP, Flownex, and GOTHIC to calculate a detailed fuel temperature distribution for predicting thermally induced diffusional radionuclide release from fuel. Please confirm that flow rates are input to THM and that THM does predict flow rates.
   b. For LWRs, the following is an important phenomenon for certain events: thermal energy from core oxidation by oxygen and steam. However, this phenomenon does not appear to be included in XSTERM. X-energy should clarify this issue.
   c. The topical report Figure 19 shows additional input to XSTERM from VSOP and Flownex for the steam generator tube rupture (SGTR) case only. Why is additional input to XSTERM needed for SGTR?

6. Steady-State Gaseous Fission Products Transport Calculations Model (GASM) and Solids Fission Product Transport Calculations Model (SOLM)
   a. The topical report Section 5.1.2 states SOLM can simulate the gaseous and halogen releases from the fuel during temperature transients. Under what situations would the gaseous and halogen release be simulated in SOLM instead of in GASM?
   b. What is the physical basis for the groupings of chemical elements in these sections?

7. Helium Pressure Boundary Model (HPBM)
   a. For LWRs, the following are important phenomenon for certain events: radionuclide phase changes, radionuclide aerosol sizes, aerosol agglomeration for radionuclides released from fuel and graphite and metallic dusts released from wear, deposition in flow irregularities (bends), and coolant flow rates. However, these phenomena do not appear to be included in XSTERM. X-energy should explain whether these phenomena are modeled. If not, explain why not.
   b. HPBM includes modeling of deposition and resuspension of layers on helium pressure boundary surfaces. What is the physical basis for assuming layers are formed?
   c. What is the physical basis for the groupings of chemical elements in the section?

8. Point Kinetics Core Simulation Model (KSIM)
    a. Section 5.1.9 states that the purpose of KSIM is to initialize the simulation's steady state and the SGTR event. It is not clear what functions KSIM performs. X-energy should explain what specific functions KSIM performs as part of the mechanistic source term approach.

Transient and Safety Analysis Methodology TR

9. Provide an overview of Figure 19.
    a. What is XDIS and what does it do?
    b. Explain the Flownex screening criteria (FSC) and how it is used in place of XSTERM.
        i. How is FSC ensured to be conservative?
    c. Explain any hand calculations that are used.
    d. How is the transition from the transient phase of an LBE to the long-term passive cooling phase made? What defines this transition point and how are parameters passed between codes?

10. Section 6.2 describes Flownex FOMs. Helium temperature and flow calculated by Flownex are used as input to VSOP. While the VSOP is used to derive the point kinetics input parameters and reactivity coefficient for calculation of reactor power (one of the most important BC) in Flownex calculation. Please explain the calculation process here as both the analyses are interdependent.

Reactor Core Design Methods and Analysis TR

11. TR Section 3.2.6 mentions that a 3-D Monte Carlo N-particle (MCNP) model is used for calculating the worth of control rods at equilibrium core conditions and generating equivalent Boron-10 concentrations for use in the VSOP model, thereby avoiding the challenges associated with the MECS approach. However, the NRC staff notes that no additional detail regarding the MCNP evaluation and generation of equivalent Boron-10 concentrations is provided in the TR. How is MCNP used in the calculations? What assumptions/approximations are made?

12. VSOP provides kinetics parameters as input to the overall evaluation model. Explain how the identified validation plans (Table 9) will sufficiently cover the range of conditions and parameters to validate VSOP's generation of kinetics parameters. Will the ASTRA experiment be used to compare kinetics parameters (TR section 5.1.1.2)?

13. Given the stochastic nature of fuel shuffling and residence time and that fuel batches are tracked using volume averaging for isotopic content/burnup, how will fuel power peaking factors, maximum fuel temperatures, and peak pebble burnups be modeled? How will burn-up and peaking limits be established and how will it be ensured that they are met?

14. TR Section 6.1 states that verification will be performed on the validation exercises and associated reports. How are the codes themselves verified? Does the quality assurance process include code verification activities that are not described in the TR?

GOTHIC and Flownex Analysis Codes Qualification TR

15. It is stated that Flownex is used during the short-term and GOTHIC for long-term analysis. The short-term transient is defined as the period at which SSCs are actively responding to an initiating event. The long-term transient is defined as the period where passive heat transfer begins and there are no active plant responses. What are the most significant shortcomings of GOTHIC as compared to Flownex that limit its use during the entire period of analysis (i.e., aside from absence of point kinetics model and possibly heat transfer models for fuel/pebble region in GOTHIC)?

16. Reference [40] contains the X-Energy Flownex Validation Plan, while the LTR contains a few examples of experimental benchmarking studies for the two codes. It is not clear if the validation plan of Reference [40] contains a complete road map for separate effects tests (SETs) and integral effect tests (IETs), including the relationship between significant (high ranked) phenomena (based on PIRT), the Flownex model elements, and the identified SETs and IETs. Please provide a summary of the code validation and assessment plan (e.g., test matrix), and justification that these reasonably bound the operational envelope for the design for any applicant referencing the LTR. Please describe how the calculation model and data V&V will be performed and documented such that all the important phenomena for the specific LBE case are appropriately accounted for to ensure that the input values are accurate.

17. Section 5.3 describes the existing GOTHIC Code V&V. Table 1 lists the test, test description, related PIRT phenomena and comments providing a reasonable description of the existing applicable GOTHIC validation. The comments in Table 1 provided a very brief summary of the validation findings, but in some instances (1) there is no summary of the accuracy of results, (2) there is a general agreement with test results but unquantified variations, and (3) indications of insufficient modeling. Other practical applications of GOTHIC were noted without a description of the findings and how they supported the GOTHIC validation. One model validation indicated that the test rig “is not suitable for validating prediction of heat losses” and in another validation a group of tests were noted without a description of the specific GOTHIC models being validated, and indication of the finding or summary of the results accuracy. Reference [69] was cited for most of the information in this section. Describe how the X-energy is planning to address these gaps in the GOTHIC verification and validation plan.

18. Section 5.4 describes the planned GOTHIC code V&V. In some cases, GOTHIC V&V planned for some models "*may be performed*" while GOTHIC code V&V planned for some models is described in some detail and "*will be performed.*" Please confirm that all of the GOTHIC V&V mentioned will be performed. Please provide a summary of how the planned GOTHIC V&V in conjunction with the existing Gothic V&V will address all of the phenomena in the LBEs for the Xe-100.

19. Appendices A and B of the submittal contain a general overview of the Flownex and GOTHIC theories, respectively. These include the general forms of various conservation equations, with limited discussion of the closure relations. However, the descriptions of the codes do not include the details of the specific models that are actually implemented in the codes. Examples of such details include:

    a. The discretized forms of the conservation equations (e.g., finite difference equations, spatial discretization, temporal discretization, actual closure relations), and
    b. Identification of models and correlation for the high ranked phenomena
    c. The validation basis of the closure relations.

    Please provide the actual forms (e.g., spatial differencing, explicit, semi-implicit, or implicit integration, etc.) of the conservation equations programmed into Flownex and GOTHIC. Demonstrate through examples the rationale for nodalization, stability, accuracy, convergence criteria, and time-step selection.