UNITED STATES
NUCLEAR REGULATORY COMMISSION
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U.S. NUCLEAR REGULATORY COMMISSION STAFF'S OBSERVATIONS REGARDING XE-100 WHITE PAPER: SEISMIC DESIGN METHODOLOGY (EPID L-2022-TOP-0047)

SPONSOR AND SUBMITTAL INFORMATION

Sponsor: X Energy, LLC (X-energy)

801 Thompson Avenue Rockville, MD 20852

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Brief Description of the White Paper: The white paper, "X Energy, LLC Licensing White Paper: Xe-100 Seismic Design Methodology," describes the risk-informed performance-based seismic design criteria development approach taken by X-energy for the Xe-100 design. X-energy stated that the approach establishes a graded, performance based seismic design criteria to ensure that structures, systems, and components (SSCs) are designed for the appropriate seismic hazards with adequate strength and serviceability requirements to meet the required performance goals.

X-energy stated that the purpose of the white paper is to provide a description of the methodologies that X-energy will use in its applications for the Xe-100 design and to seek feedback on the general acceptability:

- To outline the development of the seismic design basis for the plant SSCs, including outlining the seismic categorization and developing representative Design Response Spectra (DRS) curves for each category.

- To provide a description of the application of risk-informed, performance-based approach to the development of seismic DRS curves for generic plant design.

- To elaborate on the approach for the seismic analysis of the Reactor Building (RB) structure.

The U.S. Nuclear Regulatory Commission (NRC) staff makes no regulatory findings on this white paper, and nothing herein should be interpreted as official agency positions.

Enclosure

Action Requested: X-energy requested the NRC staff's feedback on the approach used to determine the generic plant DRS curves and the proposed seismic analyses methods for the RB. X-energy also requested the NRC staff's feedback on the seismic design basis development approach and the integration of NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition"[1], seismic analysis guidance into the Nuclear Energy Institute (NEI) 18-04, Revision 1, "Risk-Informed Performance-Based Technology Inclusive Guidance for Non-Light Water Reactor Licensing Basis Development," (ML19241A336), licensing basis development approach.

FEEDBACK AND OBSERVATIONS

Overall, the NRC staff notes that the white paper provides a reasonable risk-informed, performance-based graded approach for developing the seismic design criteria for SSCs for the Xe-100 design.

Specific NRC staff's feedback is provided below:

A) Seismic design basis (SDB) development approach

1. X-energy's designation of SDB 5D for Seismic Category I (Safety-Related (SR)) structures and SDB 3D for Seismic Category II (Non-Safety-Related with Special Treatment (NSRST)) structures generally seems reasonable and X-energy's calculation of the hazard exceedance probability is within the Design Basis Event (DBE) region of Figure 3-1, "Frequency-Consequence Target," of NEI 18-04. However, X-energy should provide a more extensive rationale and justification for selecting SDB 3D (versus SDB 4D) for Non-Safety-Related with Special Treatment (NSRST) structures.

2. Section 1.2, "Scope," of the white paper states, in part:

   Whether initially selected deterministically or probabilistically, the hazards are addressed in the site-specific probabilistic risk assessment (PRA) and can result in the identification of new licensing basis events (LBEs). When the hazards are addressed in the PRA, the response of the plant to the full frequency spectrum of the hazards will be considered and result in LBEs initiated by hazards that may appear in the anticipated operational occurrences, design basis events, and beyond design basis events (BDBE) regions.

   Section 1.2.3, "External Hazards and Component Classification," states, in part:

   > The maturing PRA will update the seismic analysis as the design progresses to ensure that seismic challenges are properly addressed and accounted for. In line with NEI 18-04, the risk for seismic hazards will be

[1] NUREG-0800, Standard Review Plan for the Review of Safety Analyses Reports for Nuclear Power Plants: LWR Edition, U.S. Nuclear Regulatory Commission. See https://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0800/index.html

> accounted for in the Frequency Consequence Curve and appropriately addressed by the integrated decision making process (IDP).

X-energy should clarify if the statements above imply that the maturing PRA and especially the site-specific PRA will be used by the IDP to confirm the adequacy of selecting SDC 3 in American Society of Civil Engineers (ASCE) and Structural Engineering Institute (SEI) Standard 43-05, “Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities,”[2] (or ASCE/SEI Standard 43-19, “Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities”[3]) for the NSRST SSCs in relation to meeting performance goals and, if needed, revise the initial SSC categorization for a specific site. The NRC staff issued two pre-decisional draft regulatory guides titled “Technology-Inclusive, Risk-Informed, and Performance-Based Methodology for Seismic Design of Commercial Nuclear Plants” (ML22276A149), and “Seismically Isolated Nuclear Power Plants” (ML22276A154). X-energy should clarify how the initial SSC categorization for seismic design and any related site-specific verification compare with the processes in pre-decisional draft regulatory guides.

3. Section 3.1, “Xe-100 Seismic Design Bases,” of the white paper states, in part:

> A graded approach is used in developing the seismic design criteria using methods outlined in ASCE Standard 43-05…for a performance-based approach to the physical design of SSCs for a nuclear facility.

X-energy should clarify the rationale/bases of why ASCE/SEI Standard 43-05 is proposed for implementing a performance-based graded approach for seismic design of SSCs for Xe-100 design rather than the most current version of the standard, ASCE/SEI Standard 43-19. The NRC staff notes that the technical basis for the “design factor” (DF in ASCE/SEI Standard 43-05 with a value greater than 1.0) and the “scale factor” (SF in ASCE/SEI Standard 43-19 with a value less than 1.0) and the equations for defining the DRS differ between ASCE/SEI Standard 43-05 and 43-19, and the differences between the editions of the standard should be reconciled or consider using the latest edition of the standard. The NRC staff also observes that more recent editions of related standards to ASCE/SEI Standard 43, “Seismic Design Criteria for Structures, Systems, & Components in Nuclear Facilities”[4], have been published, such as ASCE/SEI Standard 4-16, “Seismic Analysis of Safety-Related Nuclear Structures,”[5] ASCE/SEI Standard 7-16, “Minimum Design Loads and Associated Criteria for Buildings and Other

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[2] ASCE/SEI Standard 43-05, "Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities.” See https://ascelibrary.org/doi/book/10.1061/9780784407622
[3] ASCE/SEI Standard 43-19, “Seismic Design Criteria for Structures, Systems and Components in Nuclear Facilities.” See https://ascelibrary.org/doi/book/10.1061/9780784415405
[4] ASCE/SEI Standard 43, “Seismic Design Criteria for Structures, Systems, & Components in Nuclear Facilities.” See https://ascelibrary.org/doi/book/10.1061/asce43
[5] ASCE/SEI Standard 4-16 “Seismic Analysis of Safety-Related Nuclear Structures.” See https://ascelibrary.org/doi/book/10.1061/9780784413937 .

Structures"[6], and ASCE/SEI Standard 7-22, "Minimum Design Loads and Associated Criteria for Buildings and Other Structures"[7]. Section 3.1 of the white paper on page 9 states, in part, that "[t]he Seismic Category III curves are developed using the risk-targeted Maximum Considered Earthquake…maps and procedures in ASCE 7-16." The NRC staff notes that the seismic design basis described in ASCE/SEI Standard 7-16 involves Site Class, Risk Category and Seismic Design Category (A through F), which appear to be assigned in a different manner than in ASCE/SEI Standard 43-05. X-energy should consider if reconciliation is needed between the seismic design basis proposed for Non-Safety-Related with No Special Treatment (NST) structures with reference to ASCE/SEI Standard 43-05 and corresponding use of ASCE/SEI Standard 7-16, which are more recently published standards.

4. Section 3.1 of the white paper states, in part:

   "NST SSCs are assigned SDBs 1A through 2B…." With reference to Table 2, "Seismic Design Bases for SSCs in Different SDCs and Limit States (ASCE - 43 05)," X-energy should clarify if NST SSCs may be assigned any of SDB-1A, SDB-1B, SDB-1C, SDB-2A or SDB-2B, or any of SDB-1A, SDB-1B, SDB-2A, or SDB-2B only.

5. NEI 18-04 Table 4-1, "Summary of Special Treatments or SR and NSRST SSCs," includes additional special treatment requirements for seismic design basis for NSRST and NST SSCs with footnote 3 that reads: "[3] *SR-classified SSCs are required to perform their RSFs following a Safe Shutdown Earthquake; NSRST and NST SSCs required to meet Seismic II/I requirements (required not to interfere with the performance of SR SSC RSF's following a Safe Shutdown Earthquake)*."

   The white paper appears to lack clarity regarding addressing Seismic II/I and/or III/I requirements. X-energy should clarify how the requirements described in footnote 3 of NEI 18-04 Table 4-1 are addressed or met for NSRST and NST SSCs in the proposed seismic design basis for the Xe-100 design, especially considering that the seismic design basis will be different for SR, NSRST and NST structures.

6. Section 3.1.1, "Regulatory Basis," of the white paper states, in part, regarding the complimentary design criteria for NSRST SSCs that "… (3) the importance of the <u>safety functions</u> emphasis added to be performed."

   X-energy should consider if the phrase "safety functions" should be replaced with "risk-significant functions," "PRA safety functions," or "safety-significant functions" to be consistent with the terminology in Section 4 of NEI 18-04 as it relates to NSRSTs. Also, X-energy should clarify if the complementary design criteria could mean that the SDB for NSRST (proposed as 3D in the white paper) could be subject to change depending on the SSC and if so, what would be its implication on the proposed SDB.

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[6] ASCE/SEI Standard 7-16, "Minimum Design Loads and Associated Criteria for Buildings and Other Structures." See https://ascelibrary.org/doi/book/10.1061/9780784414248 .
[7] ASCE/SEI Standard 7-22, "Minimum Design Loads and Associated Criteria for Buildings and Other Structures." See https://ascelibrary.org/doi/book/10.1061/9780784415788

The NRC staff notes that complementary design criteria are first introduced in, "Technology Inclusive Guidance for Non-Light Water Reactors: Safety Analysis Report Content for Applicants Using the NEI 18-04 Methodology" (ML22060A190). The NRC staff has recently issued a draft regulatory guide (DG-1404, "Guidance for a Technology-Inclusive Content of Application Methodology to Inform the Licensing Basis and Content of Applications for Licenses, Certifications, and Approvals for Advanced Reactors," (ML22076A000) endorsing NEI 21-07, Revision 1 with additions and clarifications for public comments.

7. Section 3.1.4, "Soil Profiles," of the white paper states, in part:

   > Bounding soil profiles for the development of soil properties and subsequently to be used for SSI analyses are outlined in this section. Hence profiles corresponding to a relatively soft soil and hard rock are chosen to generically bound the seismic design basis for the Xe-100 plant. The conceptual design for the plant was performed using the two site-specific soil profiles for [Columbia Generating Station (CGS) and Darlington Nuclear Power Plant (DNPP)] as these are deemed to be representative of soft soil and hard rock cases thus providing adequate coverage for the broadband design curve.

   Section 3.1 also states:

   > Soil profile inputs were developed for the generic plant design to incorporate bounding values for soil properties…. The generic soil properties used for design are for softer soil and hard rock and are representative of lower and upper bounds of soil stiffness properties.

   Regarding the use of just two extreme soil profiles, as recommended in industry standards (e.g., ASCE/SEI Standard 7-16) as well as Standard Review Plan Section 3.7.2, "Seismic System Analysis," Revision 4 (ML13198A223), and considering that X-energy plans to use nonlinear soil behavior analyses, the NRC staff thinks that at least three soil/rock profiles should be considered for the generic design analyses, namely, one most representative of the majority of sites (or a Best Estimate (BE) equivalent) in addition to a lower bound (LB) profile and an upper bound (UB) profile in the evaluation of the effects of soil structural interaction (SSI). The NRC staff also notes that UB high stiffness profile should make use of LB soil damping properties and the LB soft stiffness should make use of the higher damping properties, with the BE case using representative soil damping values. Note that this comment is coming from the analogous observation that can be made from Figure 2, "Xe-100 Horizontal DRS Curve Envelope – 5% Damping," of the white paper that if only the DRS of the two bounding cases therein (namely CGS and DNPP) were considered, it would not be bounding or enveloping of the peaks of the DRS of the vast majority of the sites in between.

8. The white paper does not appear to address the operating basis earthquake (OBE) as part of the seismic design basis. X-energy should address the OBE, pursuant to Title 10 of the *Code of Federal Regulations* Part 50, Appendix S, "Earthquake

Engineering Criteria for Nuclear Power Plants," in the seismic design basis and its impact, if any, for the Xe-100 design.

B) *Approach used to determine the generic plant DRS curves*

1. Section 3.1.3, "Procedure for Development of Enveloped [Ground Motion Response Spectra (GMRS)] Curves," of the white paper states, in part:

   > The 5% damped horizontal enveloped DRS curve is generated using the GMRS curves outlined in References 2 and 3 which are then enveloped as shown in Figure 2. Only the 5% damped plots are presented here for ease of review and comparison. Additionally, these curves are also compared to the response spectra from [Regulatory Guide (RG)] 1.60, Rev. 2 [(ML13210A432)], …anchored to a [zero-period acceleration (ZPA)] of 0.3g's to demonstrate compliance.

   It is not clear to the NRC staff as to why the second sentence is made by X-energy. Perhaps the statement is made to show that the resulting DRS is broadband, but it is not clear that this is the intent. X-energy should clarify the intent.

2. In Section 3.1.3 of the white paper, Table 4, "V/H Ratios for Vertical DRS," provides values for vertical to horizontal (V/H) ratios to be used for the development of vertical design response spectra.

   X-energy should clarify whether the values in Table 4 of the white paper are appropriate for all sites across the continental U.S. Studies have shown that the V/H ratios can be significantly different across regions of the continental U.S. as well as conditioned on seismic hazard parameters such as peak ground acceleration (NUREG/CR-6728, "Technical Basis for Revision of Regulatory Guidance on Design Ground Motions: Hazard- and Risk- Consistent Ground Motion Spectra Guidelines" (ML013100232)).

3. In Section 3.1.5, "DRS Development for Seismic Category II SSCs," the white paper describes the development of the DRS for Seismic Category II SSCs.

   While the overall approach appears to be generally reasonable, it is not clear to the NRC staff whether each site, that governs the Seismic Category I bounded DRS, governs the Seismic Category II bounded DRS. Since the hazard curves used in the determination of each site-specific DRS are control point hazard curves (either on soil or rock), nonlinearity in soil response can be significantly different for varying levels of ground motion. This could result in not only varying degrees of amplitude for a specified hazard exceedance frequency, but also significantly effecting the slopes of individual hazard curves over specific hazard exceedance frequency ranges. X-energy should describe verification that the same sites governing the Seismic Category I bounded spectrum also govern the Seismic Category II bounded spectrum.

C) Proposed seismic analyses methods for the RB

1. Section 3.2.4.2, “Critical Damping Values,” of the white paper states, in part:

   > On this basis, DRS-level damping for the RB structure will be assumed for seismic analysis. For the reinforced concrete structures (including steel-plate composite (SC) members), 7-percent structural damping will be used.

   Also, Section 3.2.7.3, “SSI Analysis Code,” of the white paper states:

   > Structural materials, such as reinforced concrete and …walls, will be modelled as cracked members, commensurate with level of stress. As discussed in Section 3.2.4.2 of this report, structural damping will be commensurate with [safe-shutdown earthquake] level response, or 7 percent, from RG 1.61 [(ML070260029)].

   The NRC staff agrees that the damping values used for determining design loads and generation of in-structure response spectra should be based on consideration of the actual average response level (represented by elastic demand to capacity ratio (De/C) based on unfactored loads); however, the NRC staff observes that there is also a maximum response level for damping allowed based on the target limit state (see Chapter 3 of ASCE/SEI Standard 43) in the seismic design basis and the analysis performed. For Limit State D that is proposed in the white paper for Seismic Category I (SR) and II (NSRST) structures, the maximum response level for damping recommended in ASCE/SEI Standard 43 is Response Level 2. Accordingly, per Table 3-1 of ASCE/SEI Standard 43-19 (noting that RG 1.61, “Damping Values for Seismic Design of Nuclear Power Plants,” Revision 1 (ML070260029) and ASCE/SEI Standard 43-05 do not provide damping values for Steel Plate Composite (SC) structures), the damping values used for SC structures, based on American National Standards Institute/American Institute of Steel Construction N690-18, “Specification for Safety-Related Steel Structures for Nuclear Facilities”[8], should not exceed 5 percent versus the 7 percent proposed in the white paper.

   For in-structure response spectra generation, the special considerations and guidance in regulatory position 1.2 of RG 1.61, to use the damping-compatible with structural response should be considered and followed. Also, the material soil damping values associated with SSI analysis should be appropriately justified and NUREG-0800, Section 3.7.1, Revision 4 (ML14198A460) recommends the maximum soil damping value should not exceed 15 percent.

[8] American National Standards Institute/American Institute of Steel Construction N690-18, “Specification for Safety-Related Steel Structures for Nuclear Facilities.” See https://www.aisc.org/specification-for-safety-related-steel-structures-for-nuclear-facilities-ansi-aisc-n690-18

2. Section 3.2.4.3, “Design Time Histories,” of the white paper states, in part:

   > As the RB seismic analysis will involve nonlinear soil behavior, multiple sets of time histories will be used.… The developed time histories will meet the requirements of Option 2 of NUREG-0800, 3.7.1 Section II.1.B.…

   As described in the NUREG-0800, Section 3.7.1 guidance, the NRC staff emphasizes that for nonlinear structural analyses the number of time histories should be greater than four and sufficient technical basis for the appropriate number of time histories should be described. This would also include the approach used to demonstrate adequacy of the characteristics of the multiple time histories in terms of enveloping criteria and having sufficient power over the frequency range of interest. The NRC staff further notes that, as indicated in NUREG-0800, Section 3.7.2, Revision 4, paragraph II.1, the NRC staff will review analysis methods incorporating inelastic/nonlinear considerations and its results on a case-by-case basis. NUREG-0800, Section 3.7.2, Revision 4 also states that: “In the event the nonlinear analysis is chosen, the results of the nonlinear analysis should be judged on the basis of the linear or equivalent linear analysis [(NUREG/CP-0054, “Proceedings of the Workshop on Soil-Structure Interaction,” (ML13214A087))]”.

3. Section 3.2.6.1, “Response Spectrum Method,” of the white paper states, in part:

   > As an alternative, the 100-40-40 percent combination rule may be used in lieu of the [square root of the sum of the squares] method. Combinations of seismic response from the three earthquake components, together with variations in sign (plus or minus), will be considered.”

   If the 100-40-40 method will be implemented based on guidance other than in RG 1.92, Revision 3, “Combining Modal Responses and Spatial Components in Seismic Response Analysis” (ML12220A043), (e.g., ASCE/SEI Standard 4-16), the guidance used should be clearly described and justified.

4. Section 3.3, “Quality Assurance Program and Software Verification Approach,” of the white paper states, in part, that the “[d]esign and analyses may be performed using commercially procured software with adequate verification of performance of critical characteristics and acceptance criteria.” The NRC staff notes that verification and validation of computer programs used should be adequately documented for the intended application of the program for the Xe-100 design.

D) Integration of NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition,” seismic analysis guidance into the NEI 18-04, Revision 1, “Risk-Informed Performance-Based Technology Inclusive Guidance for Non-Light Water Reactor Licensing Basis Development” (ML22060A190), licensing basis development approach

   1. The NRC staff thinks that the proposed integration of NUREG-0800 seismic analysis guidance into the NEI 18-04 licensing basis approach, as applicable, appears to be

reasonable and practical, especially considering seismic analysis methods remain consistent for any licensing basis development approach.

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