UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

NRC FEEDBACK REGARDING SMR, LLC (HOLTEC) WHITE PAPER: 160-USNRC-072 SOIL-STRUCTURE INTERACTION ANALYSIS METHOD (EPID L-2023-LRO-0068) SPONSOR INFORMATION

Sponsor: SMR, LLC (A Holtec International Company)

Sponsor Address: Holtec International
1 Holtec Boulevard
Camden, NJ 08104

Docket /Project No(s).: 99902049

DOCUMENT INFORMATION

Submittal Date: December 18, 2023

Submittal Agencywide Documents Access and Management System (ADAMS) Accession No.: ML23352A399, supplemented with ML23352A401

Purpose of the White Paper: SMR, LLC (Holtec) stated that its white paper, 160-USNRC-072, "Soil-Structure Interaction Analysis Method," serves a dual purpose: (1) it offers an overview of the proposed Soil Structure Interaction (SSI) analysis methodology, with updates on its progress (including initial SSI analysis results) since the previous meeting on November 8, 2023, and (2) it responds to the feedback provided by the U.S. Nuclear Regulatory Commission (NRC) staff.

The white paper is a revision based on discussions of the original white paper during the November 8, 2023, public meeting.[1] The public meeting included discussion of the NRC staff questions on the original white paper that are listed in Enclosure 4 of the meeting summary.[2]

---

1 U.S. NRC, "11-08-23 Meeting Summary with SMR,LLC, a Holtec International Company, to Discuss SMR-160 Update SSI Methodology," dated January 31, 2024. See Enclosure 3 for meeting summary details. https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML23339A038.

2 U.S. NRC, "Enclosure 4 - 11-08-23 Staff Questions for Public Meeting with SMR, LLC, a Holtec International Company, to Discuss SMR-160 Update SSI Methodology," dated January 31, 2024. https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML23339A051

FEEDBACK AND OBSERVATIONS

The NRC staff feedback and observations on this white paper are preliminary and subject to change. The feedback and observations are not regulatory findings on any specific licensing matter and are not official agency positions.

The NRC staff notes that the white paper describes the approach SMR (Holtec) would use to assess the SSI of the SMR-300 reactor at a given site. The results of the SSI analysis are used for subsequent structural evaluations and defining the seismic loads for the safety-related equipment and the supporting structures within seismic Category I buildings. The white paper focuses on key portions of the SSI analysis methodology and does not include all details. The NRC staff review observations should not be construed as information needed in a subsequent revised white paper or provided in a construction permit (CP) application. Rather, the NRC staff feedback and observations are provided for consideration. The NRC staff review of a CP submitted under Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50 will focus on the adequacy of the design to provide safety and ability to comply with applicable regulatory requirements.

The NRC staff understands that the proposed SMR-300 reactor will be deeply embedded at soil sites. The containment enclosure structure (CES) of the SMR-300 design will house the steel containment structure (CS) which is connected to the reactor auxiliary building. The control building is within the reactor auxiliary building. The SMR-300 design also includes surface structures, such as the radioactive waste building, turbine building, and auxiliary building. The CS also houses the spent fuel pool (SFP) and annular reservoir (AR) between the CS and the CES (Figures 16 and 17 of the white paper). The NRC staff considers that a seismic event will generate not only the response of the concrete and steel structures but also the response of the fluid (water) in the SFP and the AR. Therefore, the analysis of the reactor design in a future license application should model both solid and fluid effects using a soil-structure-fluid interaction (SSFI) methodology, rather than considering only the solid effects (soil, structure, and water assumed as solid materials with different properties) in the SSI methodology. In addition, the fluid motion generated due to the seismic event imparts additional stresses on the containment steel and concrete structures which should be considered in the design.

The approach described in the white paper is a nonlinear time-domain SSI analysis which is not generally used in nuclear reactor design. The NRC staff notes that nonlinear SSI and SSFI analyses are inherently complex and, if used in a CP application, will be subject to significant scrutiny including, but not limited to, the computer program(s), the formulation of the selected elements, material properties used including determination of the property values, interface modeling including parameters used, time step used, and the status of verification and validation.

The NRC staff developed observations associated with the following:

- Understanding of the proposed nonlinear SSI analysis method for the seismic safety-related Category I and neighboring structures of the SMR-300 reactor,

- Evaluating the appropriateness of an SSFI methodology to assess the complex problem.

The following discussion considers both the proposed SSI analysis method in the white paper and the SSFI analysis method that appears to be the more appropriate analysis method for the design.

1. Modeling of Soil-Structure-Fluid Interactions: The NRC staff notes that SMR (Holtec) is using the LS-DYNA computer code to assess the coupled interactions among the concrete and steel structures, surrounding soil mass, and fluid (water) in the SFP and AR. In its response to NRC Question #23, SMR (Holtec) stated that a simple fluid model is and will be used to simulate the fluid (water) effects during a seismic event by assigning the solid element in the LS-DYNA code with zero shear strength. However, the NRC staff notes that this simple formulation does not simulate the sloshing which takes place in the fluid (water) during a dynamic (seismic) event. SMR (Holtec) has responded that sloshing will be a secondary effect and the water in the AR would not undergo significant sloshing without a detailed justification. SMR (Holtec) did not discuss whether sloshing would be significant in the SFP during a seismic event. The NRC staff does not agree with the SMR (Holtec) response that sloshing would be negligible (especially in the SFP) during a high seismic event and will conduct a detailed review of the SSI or SSFI analysis if a CP application is submitted using these methods.

2. Interface Modeling: SMR (Holtec) stated that “a simple surface-to-surface definition” in LS-DYNA will be used to model the contacts/interfaces between the structures and the surrounding soil mass. This LS-DYNA interface element model can simulate pure sliding and sliding with separation (gapping). The NRC staff will conduct a detailed review of the model formulation including the tests to be conducted to determine the parameter values of the model and verification and validation conducted on this model if an application is submitted with this proposed approach because potential separation of the wall/soil interface and lifting of the structural base can significantly affect the SSI or SSFI results (e.g., in-structure response spectra), including rigid body like motion of the structure (Xu et al., 2006).

The NRC staff understands that verification is a process that provides evidence that a model is solved correctly, and validation is a process that demonstrates that the correct model has been used such that the model is able to reasonably reproduce observed data (such as data from physical experiments). The level of detail provided in the white paper was not sufficient to demonstrate that interface modeling verification and validation is complete.

3. Soil Material Modeling: The material models described in the white paper generally appear to capture the nonlinear, dynamic soil behavior. The NRC staff will conduct a detailed review of the material model(s) used to simulate the soil response under seismic loads if a CP application is submitted with the proposed approach, as the strongly coupled SSI or SSFI response is expected to be sensitive to the material model(s) assumed for the surrounding soil (Xu et al., 2006). The review will also include the appropriateness of the model parameter values used and their range obtained from the site-specific geotechnical and geophysical investigations.

4. Modeling of Radiation Damping: SMR (Holtec) explained that the radiation damping is automatically addressed by the LS-DYNA model with a soil lateral boundary sufficiently remote from the structures and a viscous boundary at the bottom surface of the soil. The NRC staff believes that the radiation damping is an important parameter in an SSI analysis and how the radiation damping is modeled in the analysis presents an important distinction between the time-domain and frequency-domain SSI methodologies. Therefore, the NRC staff will conduct a detailed review if a CP application is submitted with the proposed approach.

5. Non-Vertical Wave Propagation: The NRC staff notes that this white paper describes a 1-D wave propagation mode. The NRC staff will conduct a detailed review of the rationale for not considering the non-vertically propagating seismic waves in a deeply embedded reactor. For example, the NRC staff will assess whether a 2-D or 3-D seismic wave propagation needs to be modeled in a CP application submitted with the proposed approach, especially when the analysis involves a deeply embedded structure.

6. Verification and Validation (V&V) of the Proposed Modeling Approach: SMR (Holtec) explained that a simple SSI problem of a deeply embedded nuclear structure will be analyzed using the proposed time-domain SSI analysis methodology to demonstrate that the obtained in-structure responses align well with results from the traditional system for analysis of soil-structure interaction (or SASSI) linear SSI analysis performed in the frequency-domain. As noted previously, the NRC staff believes that the SSFI methodology is more appropriate for analyzing the design. It is not clear to the NRC staff whether SMR (Holtec) is considering only one simple demonstration problem for the purpose of V&V for the proposed time-domain, nonlinear SSI or SSFI analysis methodology. The NRC staff expects SMR (Holtec) will consider a comprehensive suite of V&V example problems and tested parameters to provide confidence that the proposed SSI or SSFI methodology is applicable to solving problems with a wide range of parameters and produces accurate results. The acceptance criteria used in V&V should be consistent with the generally accepted industry practice.

7. Consideration of Uncertainties and Sensitivity Analyses: SMR (Holtec) mentioned that it will consider uncertainties of the material properties and model input parameters and conduct a sensitivity analysis. An independent peer review of the process and the results will be provided by a contractor. The NRC staff will review how SMR (Holtec) incorporates both epistemic uncertainties and aleatory variabilities into the analysis and any statistical treatments of the results if an application is submitted with the proposed methodology. The NRC staff will also review the reasonableness of the key assumptions used in the analysis and sensitivity of the outcome to these assumptions.

REFERENCES:

Xu, J., C. Miller, C. Costantino, and C. Hofmayer. 1996. “Assessment of Seismic Analysis Methodologies for Deeply Embedded Nuclear Power Plant Structures.” NUREG/CR–6896, BNL–NUREG–75410–2006.

Principal Contributors:

Amitava Ghosh, NRR/DEX/ESEB
Thomas Weaver, RES/DE/SGSEB
Sunwoo Park, NRR/DRA/APLC