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

March 27, 2019

MEMORANDUM TO: Samuel S. Lee, Chief
Licensing Branch 1
Division of Licensing, Siting,
and Environmental Assessment
Office of New Reactors

FROM: Marieliz Vera, Project Manager ***/RA/***
Licensing Branch 1
Division of Licensing, Siting,
and Environmental Assessment
Office of New Reactors

SUBJECT: U. S. NUCLEAR REGULATORY COMMISSION STAFF REPORT OF REGULATORY AUDIT FOR NUSCALE POWER, LLC; NUSCALE REACTOR INTERNALS COMPREHENSIVE VIBRATION ASSESSMENT PROGRAM AND SEISMIC ANALYSIS

On January 6, 2017, NuScale Power, LLC (NuScale) submitted a design certification (DC) application, for a Small Modular Reactor, to the U.S. Nuclear Regulatory Commission (NRC) (Agencywide Documents Access and Management System (ADAMS) Accession No. ML17013A229). The NRC staff started its detailed technical review of NuScale's DC application on March 15, 2017.

The NRC staff conducted an audit of the NuScale's reactor internals seismic analysis specifically related to the acoustic absorption analysis associated with the NuScale DC application, Final Safety Analysis Report, Section 3.9.2. The audit was initiated on December 19, 2018, and ran through January 3, 2019, in accordance with the audit plan in ADAMS (ML17118A283).

The purpose of the audit was to: (1) gain a better understanding of the NuScale design; (2) verify information; (3) identify information that may require docketing to support the basis of the licensing or regulatory decision; and (4) review related documentation and non-docketed information to evaluate conformance with regulatory guidance and compliance with NRC regulations.

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The NRC staff conducted the audit via access to NuScale's electronic reading room. The audit was conducted in accordance with the NRC Office of New Reactors (NRO) Office Instruction NRO-REG-108, "Regulatory Audits."

The publicly available version of the audit report and the audit attendee list are enclosed with this memorandum.

Docket No. 52-048

Enclosures:
1. Audit Summary – (Non-Proprietary)
2. List of Attendees
3. Audit Summary – (Proprietary)

cc w/o Enclosure 3.: DC NuScale Power, LLC Listserv

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ADAMS Accession No.: ML19072A136 *via email NRO-002

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U.S. NUCLEAR REGULATORY COMMISSION
SUMMARY AUDIT REPORT OF NUSCALE POWER, LLC, NUSCALE POWER MODULE SEISMIC ABSORPTION ANALYSIS

1.0 BACKGROUND

Title 10 of the *Code of Federal Regulations* (10 CFR) Part 52, Section 47, "Contents of applications; technical information," states that:

> *The application must contain a level of design information sufficient to enable the Commission to judge the applicant's proposed means of assuring that construction conforms to the design and to reach a final conclusion on all safety questions associated with the design before the certification is granted. The information submitted for a design certification must include performance requirements and design information sufficiently detailed to permit the preparation of acceptance and inspection requirements by the [U. S. Nuclear Regulatory Commission] NRC, and procurement specifications and construction and installation specifications by an applicant. The Commission will require, before design certification, that information normally contained in certain procurement specifications and construction and installation specifications be completed and available for audit if the information is necessary for the Commission to make its safety determination.*

On March 15, 2017, the U.S. Nuclear Regulatory Commission (NRC) accepted and docketed a standard design certification application (DCA) (Reference 1) submitted by NuScale Power, LLC (NuScale), to certify its small module reactor design.

Between May 16, 2017, and November 2, 2017, the NRC staff completed Phase 1 of the audit that included examination of NuScale's design documents, drawings, test plans, and test reports related to the NuScale Power Module (NPM) seismic analysis and reactor internals comprehensive vibration assessment program (CVAP). The NRC staff's Phase 1 audit summary report is available in Agencywide Documents Access and Management System (ADAMS) under Accession No. ML18023A091.

In TR-0916-51502, Revision 1, "NuScale Power Module Seismic Analysis," submitted to the NRC on October 2, 2018, NuScale discussed the calculation of acoustic absorption coefficient for the attenuation of acoustic loads at the interface between the pool water and the reactor building during a seismic event. The purpose of this Phase 2 audit was to review the NPM seismic analysis to verify that the acoustic absorption analysis is appropriate.

The NRC staff provided NuScale with the Phase 2 audit plan to facilitate the audit, as documented in ADAMS (ML18344A151). The NRC staff followed the NRO Office Instruction NRO-REG-108 (Revision 0), "Regulatory Audits," in performing the audit of the NuScale design specifications.

At the NRC and the NuScale office in Rockville, Maryland on December 19, 2018, staff members from the Mechanical Engineering Branch of the Division of Engineering and Infrastructure in the NRC Office of New Reactors and NRC consultants conducted a regulatory audit of the NuScale NPM seismic absorption analysis. The NRC staff reviewed

the NuScale presentation and design documents related to the NPM seismic absorption analysis. The NRC staff's observations and findings are documented in the Audit Results section.

2.0 DOCUMENTS REVIEWED

- Presentation - "Absorbing Coefficient for Pool Water and Reactor Building Floor Interaction."
- EC-F010-6124, Draft Revision 1, "Absorption coefficient for pool water and reactor building floor interaction," issued July 2018.
- TR-0118-58005, Revision 0, "Improvements in Frequency Domain Soil-Structure-Fluid Interaction Analysis."

3.0 AUDIT RESULTS

Analyzing reactor pressure vessels (RPV) and containment structures immersed in a pool of water for seismic response is new and unique to NuScale. Tools traditionally used to estimate seismic induced loads on buildings and internal structures (like SASSI) combine well-established and accepted procedures for modeling seismic wave propagation through various soil conditions and into simplified models of the buildings and structures. To properly capture the effects of the NuScale pool on seismic response, this approach is augmented. NuScale's current analysis approach applies loads from a SASSI analysis of the reactor building containing a simplified model of a NPM with various underlying soil conditions to a detailed ANSYS model of the NPM surrounded only by the pool water. However, NuScale's modeling results in excessive and unreasonable amplification of NPM response at its fundamental vertical mode. NuScale therefore investigated a means of including more realistic damping in its detailed NPM/pool model.

The staff reviewed NuScale's internal report EC-F010-6124, draft Revision 1, "Absorption Coefficient for Pool Water and Reactor Building Floor Interaction," and met with NuScale staff to discuss NuScale's methods and analyses. NuScale's pool has a vertical first acoustic resonance at [

]

NuScale developed a new Licensing Topical Report TR-0118-58005, Revision 0, "Improvements in Frequency Domain Soil-Structure-Fluid Interaction Analysis," which combines the soil structure interaction (SSI) capability of SASSI and the fluid-structure interaction (FSI) ability of ANSYS into a single analysis tool. NuScale plans to later use this methodology for combined license (COL) applications, pending NRC staff approval. A fully coupled model that NuScale developed (but did not make available during the audit) using this new methodology indicates that the [ ] acoustic mode is reasonably damped by interaction with the reactor building structure and surrounding soil. These results motivated NuScale to pursue a means of appropriately damping the [ ] vertical acoustic mode in the NPM/pool models used for design certification.

NuScale compared vertical acceleration responses of Model 1 - a fully coupled building/NPM/pool model (without soil modeling) and Model 2 - the NPM/pool-only model. In Model 1 (the fully coupled model), the reactor pool, NPM, and surrounding concrete/steel structures with some backfill around vertical walls were modeled. Seven percent damping was applied to the concrete, which is typical. The backfill material properties reflect layered soil, with damping ranging from ~5 to ~15 percent. The NRC staff verified that these damping values are consistent with those used in the SASSI analysis for the soft soil type as shown in DCA Part 2 Tier 2, Revision 2, Table 3.7.1-17, "Average Strain-Compatible Properties for CSDRS for Firm Soil/Soft Rock [Type 8]." NuScale applied a 1g {acceleration due to gravity (g)} uniform acceleration to the bottom of the concrete and computed frequency response functions (FRFs) between the location of applied acceleration and several internal locations.

Model 2 (the localized model simulates the pool and NPM only) is analyzed twice, with single NPM models included in different bays (1 and 6). NuScale also applied 1g uniform acceleration to this model, but now to the bottom of the pool water. The 1g loading was adjusted to reflect the transfer function between the bottom of the concrete floor and the bottom of the pool water (computed using Model 1). This correction is minor, shifting the peak frequency slightly.

NuScale compared the FRFs of Model 1 to those of Model 2. The FRFs in Model 2 are extremely conservative, with very high peaks near the [
]. These peaks are not realistic, due to the fact that there is no damping in the pool water of the NPM/pool model. A reasonable means of adding damping to the water is to apply wall absorption coefficients along the floor in the ANSYS model. Per Section 7.1.3, "Surface Impedance Boundary," of the documentation of ANSYS Version 18.2 User Manual, applying an absorption coefficient effectively sets a wall impedance (Z_{wall}) as a multiple of the water impedance (Z_{water}):

$$\frac{Z_{wall}}{Z_{water}} = \frac{1+\sqrt{1-a}}{1-\sqrt{1-a}}$$

Note that if alpha (a) is 0 (no absorption), the wall impedance is infinite (rigid wall), which was used by NuScale in its original analysis. If alpha is 1, the impedance ratio is unity, and all waves are absorbed by the floor. By trial and error, NuScale tuned an absorption coefficient of 0.75 (as reported in TR-0916-51502, Revision 1) to best match the responses of the full and NPM/pool model. Using the equation above with an alpha of 0.75 gives an impedance ratio of 3. However, to ensure conservatism, NuScale will revise TR-0916-51502, to use a coefficient of [
]

The staff determined that the actual impedance ratio between water and concrete is about 5, assuming material properties for water of density=1000 kg/m^3 and sound speed of 1500 m/s, and for concrete density of 2400 kg/m^3 and sound speed of 3000 m/s. Therefore, the alpha of [
] is reasonable and actually conservative (a higher impedance ratio leads to more acoustic wave reflection and less absorption). Note that it is also reasonable for NuScale to apply the absorption coefficients to the side walls, which should further reduce vibration and acoustic pressure amplitudes.

At the audit, NuScale engineers also provided vibration and acoustic pressure distributions at [
] to help the staff visualize the behavior of the pool, NPM, and building. The response at [

] shows strong coupling between the fundamental NPM resonance and the floor and building, with the concrete walls bending with low order plate-like motion. The backfill also vibrates, as does the ceiling. This strong coupling confirms that damping induced by the surrounding structure on the pool water occurs, and that simulating damping in a water-only model applying absorption coefficient on the floor is reasonable.

4.0 AUDIT ATTENDEES

- Yuken Wong, NRO Senior Mechanical Engineer (NRC), Audit Lead
- Timothy Lupold, NRO/DEI/MEB Branch Chief (NRC)
- Stephen Hambric (NRC Consultant)
- David Ma (NRC Consultant)
- Marieliz Vera Amadiz, NRO Project Manager (NRC)
- Marty Bryan (NuScale)
- J.J. Arthur (NuScale)
- Dylan Addison (NuScale)
- Tamas Liszkai (NuScale)
- Heqin Xu (NuScale)

U.S. NUCLEAR REGULATORY COMMISSION
SUMMARY AUDIT REPORT OF NUSCALE POWER, LLC, NUSCALE POWER MODULE SEISMIC ABSORPTION ANALYSIS

List of Attendees

Name	Organization
S. Hambric	U.S. Nuclear Regulatory Commission (NRC)
T. Lupold	NRC
D. Ma	NRC
M. Vera	NRC
Y. Wong	NRC
Dylan Addison	NuScale Power LLC. (NuScale)
J.J. Authur	NuScale
Marty Bryan	NuScale
Tamas Liszkai	NuScale
Heqin Xu	NuScale