July 31, 2019

Docket No. 52-048

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
One White Flint North
11555 Rockville Pike
Rockville, MD 20852-2738

SUBJECT: NuScale Power, LLC Supplemental Response to NRC Request for Additional Information No. 427 (eRAI No. 9408) on the NuScale Design Certification Application

REFERENCES:
1. U.S. Nuclear Regulatory Commission, "Request for Additional Information No. 427 (eRAI No. 9408)," dated April 17, 2018
2. NuScale Power, LLC Response to NRC "Request for Additional Information No. 427 (eRAI No.9408)," dated July 25, 2018
3. NuScale Power, LLC Response to NRC "Request for Additional Information No. 427 (eRAI No.9408)," dated February 8, 2019
4. NuScale Power, LLC Response to NRC "Request for Additional Information No. 427 (eRAI No.9408)," dated July 26, 2019 (ML19207A257)
5. NuScale Power, LLC Response to NRC "Request for Additional Information No. 427 (eRAI No.9408)," dated July 26, 2019 (ML19207B381)

The purpose of this letter is to provide the NuScale Power, LLC (NuScale) supplemental response to the referenced NRC Request for Additional Information (RAI).

The Enclosures to this letter contain NuScale's supplemental response to the following RAI Question from NRC eRAI No. 9408:

- 03.09.02-74

The responses to RAI Questions 03.09.02-73, 03.09.02-75, 03.09.02-76 and 03.09.02-77 were previously provided in References 2, 3, 4 and 5. This completes all responses to eRAI 9408.

Enclosure 1 is the proprietary version of the NuScale Supplemental Response to NRC RAI No. 427 (eRAI No. 9408). NuScale requests that the proprietary version be withheld from public disclosure in accordance with the requirements of 10 CFR § 2.390. The proprietary enclosures have been deemed to contain Export Controlled Information. This information must be protected from disclosure per the requirements of 10 CFR § 810. The enclosed affidavit (Enclosure 3) supports this request. Enclosure 2 is the nonproprietary version of the NuScale response.

This letter and the enclosed responses make no new regulatory commitments and no revisions to any existing regulatory commitments.

If you have any questions on this response, please contact Marty Bryan at 541-452-7172 or at mbryan@nuscalepower.com.

Sincerely,

Zackary W. Rad
Director, Regulatory Affairs
NuScale Power, LLC

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Enclosure 1: NuScale Supplemental Response to NRC Request for Additional Information eRAI No. 9408, proprietary

Enclosure 2: NuScale Supplemental Response to NRC Request for Additional Information eRAI No. 9408, nonproprietary

Enclosure 3: Affidavit of Zackary W. Rad, AF-0719-66516

Enclosure 1:

NuScale Supplemental Response to NRC Request for Additional Information eRAI No. 9408, proprietary

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Enclosure 2:

NuScale Supplemental Response to NRC Request for Additional Information eRAI No. 9408, nonproprietary

Response to Request for Additional Information
Docket No. 52-048

eRAI No.: 9408
Date of RAI Issue: 04/17/2018

NRC Question No.: 03.09.02-74

10 CFR 50, Appendix A, GDC 4 requires structures, systems, and components important to safety shall be designed to accommodate the effects of and to be compatible with the environmental conditions associated with normal operation, maintenance, testing, and postulated accidents. In the NuScale design the helical Steam Generator (SG) is part of the reactor internals FIV assessments. Primary coolant flows downward over the SG tubes, and will generate vortices over the lowest tubes (where no downstream tube or other structures can disrupt the vortices). These vortices could lock-in to structural modes of the tubes. Fluid Elastic Instability (FEI) could also occur, where the tubing array could vibrate with extremely high amplitudes. During the audit from May 16, 2017, through November 2, 2017, the staff finds that NuScale has evaluated the possibility of VS-lock-in and FEI using guidelines from the ASME Boiler and Pressure Vessel Code Section III Nonmandatory Appendix N-1300 (Flow- Induced Vibration of Tubes and Tube Banks). NuScale also evaluates the effects of turbulent buffeting due to primary and secondary coolant flows.

NuScale's estimated margins of safety against VS-lock-in and FEI are small, and are based on potentially non- conservative modeling and assumptions, including the following.

- NuScale uses an estimated gap velocity based on a CFD RANS analysis of the reactor coolant flow. The CFD analysis treats the SG tube array as a porous medium with an assumed loss coefficient, and does not model the spatial variation of flow across the annulus. Pressure and temperature gradients may lead to non-uniform flow across the annulus, and higher localized velocities near some tubes.
- In the FEI analysis with postulated inactive tube supports, NuScale switches from using the gap velocity to a lower averaged velocity. The basis for assuming a lower averaged velocity for the FEI analysis with inactive supports is unacceptable to the staff because ASME B&PV Code Section III Appendix N-1330 specifies gap velocity for FEI analysis.

- NuScale states qualitatively that the inactive support FEI analyses are not applicable since all supports should be active under prototypic conditions. No detailed analyses or testing is provided to substantiate these statements. The clearances between tube and tube supports are cited in the CVAP, and the turbulent buffeting (TB) degradation analysis report, which state that the estimated root mean square (RMS) displacements due to TB are smaller than the radial clearances.
- NuScale assumes {{ }}[2(b),(c),ECI] damping for VS and FEI analyses, which has not yet been substantiated. Regulatory Guide (RG 1.20), Rev. 3 states that damping greater than 1% should be substantiated with measurements. If the higher damping is due to postulated intermittent contact with the supports, this contact could accelerate wear and failure.
- Coarse beam finite element (FE) structural models were used to estimate modal frequencies without mesh convergence studies. The resonance frequencies calculated from FE models decrease as mesh density is increased. Also, the SG resonance frequencies cited in {{ }}[2(b),(c)], "Fluid Elastic Instability Analysis of Steam Generator Tubes" and {{ }}[2(b),(c)], "Vortex Shedding Evaluation for Reactor Vessel Internals and Steam Generator" do not appear to be consistent with those in {{ }}[2(b),(c)], "Steam Generator Structural Model".
- NuScale suggests that the FEI constants (C = 4.51 and a = 0.52) from Chen's helical SG tubing study (Journal of Sound and Vibration, 91 (4), 539-569, 1983) are more appropriate than those of Connors cited in ASME B&PV Code Section Appendix N-1330. However, unlike the Connors coefficients which bound 90% of measured data, the Chen coefficients used by NuScale fit the mean of the measured data, such that 50% of FEI conditions are at lower critical velocities. Chen's earlier publication (Journal of Sound and Vibration 78(3) 355-381, 1981) specifies a lower C = 2.31 to bound all measured data.
- SIET Test Facility (TF)2 test data show spectral peaks at frequencies which may correspond to those of low-order tube resonances. These peaks are most prominent for prototypic conditions which include boiling secondary coolant flow. It is possible the peaks are caused by VS and/or FEI.

NuScale's TB analysis also contains non-conservative assumptions, not taking into account strong pressure fluctuation spectral peaks observed in the SIET TF1 secondary flow testing. Furthermore, NuScale's TB degradation analysis assumes nominal clearances between the SG tubing and supports. However, the TB, VS, and FEI flow-induced vibration analyses state that the tubes will be in strong contact with the supports, and structural FE models assume rigid boundary conditions in the radial directions. If the tubes and supports are in contact, fretting and wear will be more significant than estimated in the current TB degradation analysis assuming nominal clearances. Finally, NuScale has not provided TB analyses of the SG tube support cantilevers.

NuScale is requested to provide the following regarding the SG tubing and supports. Alternatively, NuScale may propose other options to resolve the staff's concerns identified above.

1. Quantify the impacts of the potential non-conservatisms in the VS lock-in and FEI evaluations on fatigue and wear damage including: potential flow speed nonuniformities across the annulus surrounding the SG and potentially unconverged FE structural models. Or, provide quantitative justification why these potential non-conservatisms are not significant. Provide data from any detailed analyses and/or tests which substantiate the analysis inputs. Provide updated FEI assessments using bounding results and parameters (rather than averaged) from Chen's 1981 (JSV, 78 (3), 355-381) and 1983 (JSV, 91 (4), 539-569) papers. In particular, compare NuScale SG tubing mode reduced critical flow velocities to those in Table 8 of the Chen 1983 paper and quantify the impacts of the vibration of any modes which may be susceptible to FEI.

2. Provide the technical justification for performing the FEI analysis with inactive tube supports with averaged velocity, rather than the typically used gap velocity.

3. Provide quantitative analyses and/or test data, and technical justification to support the statements that SG tubes cannot have inactive supports in operating conditions.

4. The NuScale CVAP measurement program consists of separate effects testing for the SG tubes. Provide the test plan for upcoming SIET TF3 testing, including details on the test structures, boundary conditions, instrumentation, primary and secondary coolant temperatures and flow rates, planned tests, pre-test estimates, and acceptance criteria that will provide confidence the test results will be prototypic and bounding for the NuScale design, or provide a revised CVAP report which addresses all the issues identified above. In particular, explain what data will be needed to substantiate the assumed {{ }}2(b),(c), ECI damping for VS and FEI conditions. Explain how these test data will not be affected by any damping induced by instrumentation or non-prototypic boundary conditions. If no secondary coolant will be used, reconcile this decision against the data

from the TF2 tests which show strong low-frequency spectral response peaks in the presence of boiling, flowing secondary coolant (item 5).

5. Provide a data analysis of the SIET TF2 tests which showed strong low frequency {{ }}[2(b),(c), ECI] spectral peaks in vibration measurements, particularly in the presence of boiling secondary coolant flow. Explain the mechanism(s) which caused these peaks. If the peaks are due to VS/lock-in and/or FEI quantify the potential impacts on SG tubing and support fatigue and wear.

6. Quantify the impacts of the strong spectral peaks observed in the SIET TF1 testing on SG tubing and support fatigue and wear damage. If simplified random analyses are used (such as the Brenneman method) for TB analyses, demonstrate that those methods are implemented appropriately and are bounding using a simple, but representative, benchmark problem.

7. Provide expected RMS displacements due to both VS loading and updated TB analyses along with fatigue and wear damage analyses due to impact and fretting. The VS response analyses should be consistent with any updates made to address item 1. These analyses should address the effects of static deflections of the structures due to cross flow, gravity, thermal, buoyancy, secondary internal flow inertia and other effects which may reduce or eliminate clearances between the tube and tube supports or tube to tube.

8. Provide a summary of TB analyses of the SG tube support cantilevers.

9. Provide the resolution for the concerns cited in Appendix G of {{ }}[2(b),(c)] regarding the design of the SG supports, cantilevers, and welds. The comments in Appendix G are:

   - an assumed zero gap between the riser and tube support cantilever;
   - an uncontrolled gap between the outer tube column support and RPV, with possible detachment of the tube and tube column support at lower elevations (where VS and FEI is possible);
   - an unsupported column support above the riser at the innermost location such that the tubing could become detached from the supports;

- an uncontrolled spacing at the tops and bottoms of the tube column supports that could lead to loss of radial motion resistance;
- welds between stainless steel tube support bars and cantilevers and the carbon steel RPV, and welds of the tube support bar directly to cladding;
- uniqueness of all tube column supports, complicating assembly and leading to inadequate tube support if assembly errors occur.

Update the comprehensive vibration assessment program report TR-0716-50439 or other appropriate documentation in the design certification package to include a summary of the requested information.

NuScale Response:

The following responses correspond to the numbered items in the question:

1. Updated vortex shedding (VS) and fluid elastic instability (FEI) analysis results are provided in Sections 3.2.1 and 3.2.2 of the CVAP Analysis technical report, TR-0716-50439. For FEI, NuScale's reduced critical velocity range for all columns, elevations within the tube bundle, and tube support boundary conditions is {{ }}$^{2(b),(c),ECI}$, which is below the critical velocity range of 1.46 -1.57 cited in Table 8 of the Chen 1983 paper for the test runs without the exciter installed. The system mass damping for the reduced critical velocities cited in the Chen 1983 paper are not described, but are expected to be lower than the NuScale system mass damping, based on the damping values reported in the paper. Analysis input uncertainties related to modal response and velocity for VS and FEI analyses are documented in Sections 5.1.3 and 5.1.4 of the CVAP Measurement and Inspection Plan technical report,TR-0918-60894. All finite element models used in the design analysis are converged. Mesh sensitivity studies have been performed to demonstrate that the mesh is acceptable. The TR-0716-50439 and TR-0918-60894 document the various mesh sensitivity studies performed.

   Radial non-uniformities in the radial velocity are not relevant for VS, because VS occurs at the exit of the tube bundle and approach velocity non-uniformities dissipate after passing through the array of SG tubes. Non-uniformities may exist for the upper tubes in the bundle; however, these occur in nearly all tube bundle designs and are also present in the test data used to develop the Connors' constant curve fits. As shown in Table 8 of the Chen 1983 paper, the preliminary runs with less uniform approach velocity have reduced velocities that are similar to Runs 3 and 4, which utilized a screen flow equalizer to provide a uniform approach velocity. Gap velocity has been calculated in accordance with ASME BPVC N-1331.1.

2. The FEI analysis has been revised and results are provided in Section 3.2.1 of TR-0716-50439. Fixed and sliding steam generator (SG) tube support boundary conditions have been evaluated. These boundary conditions represent the range of expected tube support conditions, and are in agreement with the build-out modal testing that has been completed for the TF-3 test specimen (Section 3.4 of TR-0918-60894). Gap velocity has been calculated in accordance with ASME BPVC N-1331.1.
3. A thermal expansion analysis of the SG tube bundle, supports, reactor pressure vessel (RPV), and riser shows that the different rates of thermal expansion cause steady state forces on the tubes. These forces maintain contact at the tube to tube support interface. Additionally, preliminary modal testing results for the TF-3 test specimen indicate that modal frequencies are consistent with active supports. The TF-3 flow testing is performed at room temperature conditions, and do not account for the increased forces expected at normal operating conditions due to thermal expansion, which is a conservative bias in the test design. The selected boundary conditions for the SG tubes, as well as the FEI methodology, are to be validated as part of the TF-3 post-test analysis, as described in Sections 3.4 and 4.5.3 of TR-0918-60894.
4. TF-3 validation testing details, including details on the test specimen, boundary conditions, instrumentation, primary and secondary side temperatures and flow rates, planned tests, pre-test estimates, and acceptance criteria, are addressed in TR-0918-60894, Section 5.1. The TF-3 test specimen does not provide for secondary coolant, so there is no information regarding secondary coolant temperatures or flow rates. The assumed damping value is to be validated by the TF-3 test data. The input and measurement uncertainty in this value, and the bias due to instrumented tubes, is accounted for in the pre-test prediction, in order to inform the expected onset of FEI for the test, and the allowable range for validation. See Section 5.1.3 and 5.1.4 of TR-0918-60894 for additional details. The TF-3 test is tracked as part of Test 72 in FSAR Section 14. Acceptance criteria have been added to the test description in FSAR Table 14.2-72. The TF-3 test consists of in-air and in-water modal testing to characterize the frequencies and damping values, which will help reduce uncertainty in the flow testing measurements. Additionally, the revised VS analysis only assumes {{ }}[2(b),(c), ECI] damping. The bias related to the lack of secondary coolant and having instrumentation within the instrumented SG tubes is accounted for in the pre-test predictions. See Item 5 below for discussion of where information related to low frequency strain responses is located in the technical report.

5. The analysis of the low frequency strain data is added to Section 3.2 of TR-0918-60894. Analysis of the TF-2 strain gauge data indicates that the low frequency strain response is due to thermal strains caused by oscillations in fluid conditions inside the tube. The peaks are not due to FIV.
6. Analysis of the strain response due to pressure PSDs, based on the TF-1 data, is added to Section 3.2 of TR-0918-60894. The low frequency pressure data is consistent with pressure oscillations throughout the test loop, potentially due to the pumping frequency, and are not consistent with turbulence within the tube. The analysis of the cause of the pressure content at approximately {{ }}$^{2(b),(c), ECI}$ Hz is inconclusive, but analysis shows that the low magnitude and high frequency of those pressure oscillations cause a negligible strain response in the tubes. Section 3.2 of TR-0918-60894 discusses the benchmarking problems that compare the turbulent buffeting methodology to the ANSYS Random Vibration method for a simple tubular geometry.
7. The safety margin due to TB is updated in Section 3.2.3 of TR-0716-50439. The pressure PSD used for the SG tube bundle is based on bounding data from tube bundle testing, and contains a region of increased pressure fluctuations between reduced frequencies of 0.1 and 0.4 that is attributed to VS. Therefore, the VS response (not due to lock-in) is included in the TB safety margin. Static forces on the tubes due to thermal expansion are included in the impact fatigue calculations to add justification for not using the overly conservative assumption of inactive tube supports. Using active supports is consistent with the preliminary modal testing of the TF-3 test specimen. The selected boundary conditions for the SG tubes, as well as the TB displacement response, are to be validated as part of the TF-3 test post-test analysis, as described in Sections 3.4 and 4.5.1 of TR-0918-60894.
8. Discussion of the TB analysis of the lower SG support is added to Section 3.2.3 of TR-0716-50439. The displacement response and fatigue usage of the lower SG support is negligible due to the stiffness of the cantilevered support.
9. The cited calculation has since been revised. The recommendations from the previous revision Appendix G have been dispositioned. The following bullet points are summaries of how the recommendations were resolved.

   - The length of the lower SG support has been modified to add a gap between the riser and the end of the lower SG support.
   - The design of the riser backing strips has been modified so that the thickness of the strips are machined to-fit to eliminate the nominal gap during manufacturing. Thermal expansion during power operations will close any remaining clearances. In the lower portion of the SG where the RPV inner diameter expands, there are no credible forces

that would only affect the outer column(s) and provide sufficient displacement for the tube to become detached.

- The highest tubes in column 1 have the tightest bend radius to the integrated steam plenum. These tubes have shorter top transition bend spans compared to the lower tubes in column 1. There are no credible forces that would affect just the tubes of column 1 to create enough inward displacement to cause these tubes to become detached. The uppermost tabs for the lower tubes in column 1 are below the top of the riser and are supported in both radial directions.
- The radial spacing of the SG tube supports is controlled by the interfaces between the RPV, tube supports, and the upper riser. Radial forces are transferred through these interfaces and do not depend on the spacing at the upper and lower SG supports.
- The lower SG support attachment is modified to be welded to a weld buildup on the base metal of the RPV. The dissimilar coefficients of thermal expansion at the support welds, including the weld between the upper SG support and the cladding of the integrated steam plenum, are to be considered in the ASME BPVC stress analysis. The stress analysis ensures that connections between the RPV and both SG supports are suitable for the applicable loads, and include dead weight of the SG on the upper SG support, for the life of the components.
- SG tube support components are reused as much as possible. Part numbers are organized by column for simplicity. Part numbers are required to be permanently marked on the components where possible. Protection against installation errors are handled by the NQA-1 process of the manufacturer. Many installation errors are prevented due to the geometrical differences between columns. For example, column 1 tubes are not compatible with column 2 supports due to the alternating direction of the tube helices. Column 1 tubes are also not compatible with column 3 supports due to the different number of helical turns.

Impact on DCA:

The CVAP Technical Report TR-0716-50439, the CVAP Measurement and Inspection Plan Technical Report TR-0918-60894, and the FSAR Tier 2 Section 14 have been revised as described in the response above. The technical report revisions will be submitted separately. The revisions to FSAR Section 14 were included with the markup provided with the response to eRAI 8884 Question 03.09.02-10, submitted July 25, 2019.

Enclosure 3:

Affidavit of Zackary W. Rad, AF-0719-66516

NuScale Power, LLC

AFFIDAVIT of Zackary W. Rad

I, Zackary W. Rad, state as follows:

1. I am the Director, Regulatory Affairs of NuScale Power, LLC (NuScale), and as such, I have been specifically delegated the function of reviewing the information described in this Affidavit that NuScale seeks to have withheld from public disclosure, and am authorized to apply for its withholding on behalf of NuScale.
2. I am knowledgeable of the criteria and procedures used by NuScale in designating information as a trade secret, privileged, or as confidential commercial or financial information. This request to withhold information from public disclosure is driven by one or more of the following:
   a. The information requested to be withheld reveals distinguishing aspects of a process (or component, structure, tool, method, etc.) whose use by NuScale competitors, without a license from NuScale, would constitute a competitive economic disadvantage to NuScale.
   b. The information requested to be withheld consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), and the application of the data secures a competitive economic advantage, as described more fully in paragraph 3 of this Affidavit.
   c. Use by a competitor of the information requested to be withheld would reduce the competitor's expenditure of resources, or improve its competitive position, in the design, manufacture, shipment, installation, assurance of quality, or licensing of a similar product.
   d. The information requested to be withheld reveals cost or price information, production capabilities, budget levels, or commercial strategies of NuScale.
   e. The information requested to be withheld consists of patentable ideas.
3. Public disclosure of the information sought to be withheld is likely to cause substantial harm to NuScale's competitive position and foreclose or reduce the availability of profit-making opportunities. The accompanying Request for Additional Information response reveals distinguishing aspects about the method by which NuScale develops its CVAP analysis.

   NuScale has performed significant research and evaluation to develop a basis for this method and has invested significant resources, including the expenditure of a considerable sum of money.

   The precise financial value of the information is difficult to quantify, but it is a key element of the design basis for a NuScale plant and, therefore, has substantial value to NuScale.

   If the information were disclosed to the public, NuScale's competitors would have access to the information without purchasing the right to use it or having been required to undertake a similar expenditure of resources. Such disclosure would constitute a misappropriation of NuScale's intellectual property, and would deprive NuScale of the opportunity to exercise its competitive advantage to seek an adequate return on its investment.

4. The information sought to be withheld is in the enclosed response to NRC Request for Additional Information No. 427, eRAI 9408. The enclosure contains the designation "Proprietary" at the top of each page containing proprietary information. The information considered by NuScale to be proprietary is identified within double braces, "{{ }}" in the document.
5. The basis for proposing that the information be withheld is that NuScale treats the information as a trade secret, privileged, or as confidential commercial or financial information. NuScale relies upon the exemption from disclosure set forth in the Freedom of Information Act ("FOIA"), 5 USC § 552(b)(4), as well as exemptions applicable to the NRC under 10 CFR §§ 2.390(a)(4) and 9.17(a)(4).
6. Pursuant to the provisions set forth in 10 CFR § 2.390(b)(4), the following is provided for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld:
   a. The information sought to be withheld is owned and has been held in confidence by NuScale.
   b. The information is of a sort customarily held in confidence by NuScale and, to the best of my knowledge and belief, consistently has been held in confidence by NuScale. The procedure for approval of external release of such information typically requires review by the staff manager, project manager, chief technology officer or other equivalent authority, or the manager of the cognizant marketing function (or his delegate), for technical content, competitive effect, and determination of the accuracy of the proprietary designation. Disclosures outside NuScale are limited to regulatory bodies, customers and potential customers and their agents, suppliers, licensees, and others with a legitimate need for the information, and then only in accordance with appropriate regulatory provisions or contractual agreements to maintain confidentiality.
   c. The information is being transmitted to and received by the NRC in confidence.
   d. No public disclosure of the information has been made, and it is not available in public sources. All disclosures to third parties, including any required transmittals to NRC, have been made, or must be made, pursuant to regulatory provisions or contractual agreements that provide for maintenance of the information in confidence.
   e. Public disclosure of the information is likely to cause substantial harm to the competitive position of NuScale, taking into account the value of the information to NuScale, the amount of effort and money expended by NuScale in developing the information, and the difficulty others would have in acquiring or duplicating the information. The information sought to be withheld is part of NuScale's technology that provides NuScale with a competitive advantage over other firms in the industry. NuScale has invested significant human and financial capital in developing this technology and NuScale believes it would be difficult for others to duplicate the technology without access to the information sought to be withheld.

I declare under penalty of perjury that the foregoing is true and correct. Executed on July 31, 2019.

Zackary W. Rad