NuScaleDCRaisPEm Resource

From:	Cranston, Gregory
Sent:	Tuesday, April 17, 2018 3:44 PM
To:	NuScaleDCRaisPEm Resource
Cc:	Lee, Samuel; Tabatabai, Omid; Lupold, Timothy; Wong, Yuken; Chowdhury, Prosanta
Subject:	PROP Request for Additional Information No. 427 eRAI No. 9408 (3.9.2) PROP
Attachments:	Request for Additional Information No. 427 (eRAI No. 9408)-P.pdf

Attached please find NRC staff's request for additional information (RAI) concerning review of the NuScale Design Certification Application.

Please submit your technically correct and complete response within 60 days of the date of this RAI to the NRC Document Control Desk.

If you have any questions, please contact me.

Thank you.

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Docket No. 52-048
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QUESTIONS

03.09.02-73

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 reactor design, the control rod drive shafts (CRDS) and in-core instrument guide tubes (ICIGT) are exposed to cross flow above the upper riser. NuScale has evaluated the possibility of shed vortices induced by the cross-flow locking in to structural resonances of the CRDS and ICIGT using guidelines from the ASME Boiler and Pressure Vessel Code III Nonmandatory Appendix N-1300 (Flow-induced vibration of Tubes and Tube Banks). During the audit from May 16, 2017, through November 2, 2017, the staff finds that NuScale estimates small margins of safety for vortex shedding (VS) lock-in for both the CRDS and ICIGT structures, but does not plan to test either component until after prototype manufacturing. The proposed "factory testing" is limited to modal analysis in air conditions. There are several potential non-conservative aspects to NuScale's VS analyses that may reduce or eliminate the reported margins of safety against VS lock-in, including those below.

- NuScale uses averaged velocity in the cross-flow region from a computational fluid dynamics (CFD) Reynolds Averaged Navier Stokes (RANS) analysis of the reactor flow (the peak velocity is nearly twice as high as the averaged velocity). Using averaged velocity will estimate lower FIV forces which will be non-conservative.

- NuScale assumes that the holes in the CRDS support plates provide rigid in-plane boundaries on the ICIGT and CRDS structures, when there appear to be substantial clearances in the CRDS holes (to allow shaft motion), and small clearances in the ICIGT support holes (but not small enough to ensure rigid in-plane boundaries). These clearances are cited in the Turbulent Buffeting (TB) degradation analyses, which state that the estimated RMS displacements due to TB are smaller than the radial clearances.

- Coarse beam finite element (FE) structural models were used to estimate CRDS and ICIGT modal frequencies without mesh convergence studies. Resonance frequencies calculated from FE models decrease as mesh density is increased, and may be biased high in NuScale's analyses.

NuScale's TB degradation assessments may also be nonconservative given the concerns below.

- As with VS analyses, NuScale appears to use averaged instead of peak velocities as inputs to their assumed forcing functions. However, the assumed forcing functions, as delineated in Section 3.2.3 of the CVAP, are based on peak (also referred to as free stream), not averaged velocities.

- NuScale uses a simple formula to estimate average crossing frequencies. Crossing frequency is defined as an effective modal participation-weighted mean frequency of the structure in M.K. Au-Yang's "Flow-Induced Vibration of Power and Process Plant Components: A Practical Workbook," 2001, ASME Press. The estimated crossing frequency for the CRDS is about half that of the first resonance frequency, which may not be conservative and correspondingly reduces the number of damage cycles by half.

- It appears that NuScale has used simplified random analysis procedures for some of the TB assessments (such as the Brenneman method) which have not been shown to be bounding or implemented appropriately.

- While the TB degradation documents assume nominal clearances between the CRDS and ICIGT and CRDS support plate holes, the VS documents assume zero clearance and rigid boundaries in the radial direction. If the CRDSs and ICIGTs are indeed contacting the hole edges, additional wear and impact damage will occur.

NuScale is requested to provide the following regarding the CRDS and ICIGT structures. 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 evaluations on fatigue and wear damage including: maximum vs. averaged cross-flow velocities, use of active boundaries in the CRDS plates in spite of large clearances, and potentially unconverged FE structural models. Provide data from any detailed analyses and/or tests which substantiate the VS analysis inputs.
2. Quantify the impacts of the apparent non-conservatisms in the TB evaluations on fatigue and wear damage including: possible use of averaged rather than peak velocities for forcing functions, use of active boundaries in spite of large clearances, potentially unconverged FE structural models, and crossing frequencies which are less than the fundamental resonance frequency of the structures. Or, provide justification regarding why these potential non-conservatisms do not exist. If simplified random analyses are used (such as the Brenneman method), demonstrate that those methods are implemented appropriately and are bounding using a simple, but representative, benchmark problem.
3. Provide the expected RMS displacements due to both VS loading and TB analyses (reflecting any updates based on responses to items 1 and 2 along with fatigue and wear damage estimates due to impact and fretting. Fatigue analyses should include assessments of alternating stress intensities at welds and other joints computed using standard concentration and weld factors. Explain the effects on VS and TB due to any static deflections of the structures due to cross flow, gravity, thermal, buoyancy and other effects which may reduce or eliminate clearances between the CRDS and ICIGT structures and holes in the CRDS support plates.
4. The NuScale CVAP measurement program consists of factory testing for the CRDS and ICIGT. Provide a summary of the factory test plan for the CRDS and ICIGT structures, including details on the test structures, boundary conditions, instrumentation, planned tests, pre-test estimates, and acceptance criteria. —

Update the comprehensive vibration assessment program report TR-0716-50439, as appropriate to include a summary of the requested information.

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 [1.5%] 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 [EC-A014-2911, Rev. 2], "Fluid Elastic Instability Analysis of Steam Generator Tubes" and [EC-A023-2160, Rev. 1], "Vortex Shedding Evaluation for Reactor Vessel Internals and Steam Generator" do not appear to be consistent with those in [EC-A014-3306, Rev. 2], "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 [1.5%] 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 [(18-40 Hz)] 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 [EC-A014-3306, Rev. 2] 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.

03.09.02-75

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. During the audit from May 16, 2017, through November 2, 2017, the staff finds that NuScale has not measured or simulated reasonable flow-induced forcing functions for the CRAGT structures. Although several internal NuScale documents state that the CRAGT flow-induced forces are not known and that the flow fields do not resemble those of simple flows cited in the literature, no measurements of these flows or forces have been conducted. Assuming the simplified flow forces led to an estimated [95%] wall thickness degradation. The staff is unable to determine if this significant wall degradation impacts safety, or if more severe wall degradation may occur due to more complex flows through and around the CRAGTs.

NuScale is requested to provide the following information. Alternatively, NuScale may propose other options to resolve the staff's concerns identified above.

1. summarize the operating history of similar CRAGT designs in other currently operating plants,

2. define the maximum acceptable wall thickness degradation for the CRAGTs before replacement is needed,
3. explain the safety implications associated with complete wall thickness degradation of the CRAGTs, and
4. explain how more prototypic flow fields and forces will be estimated and applied to updated structural response analyses, or how tests might be used to show that CRAGT vibration and/or strain is negligible.

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.

03.09.02-76

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. The only reactor vessel internals (RVI) component evaluated explicitly for leakage flow instability (LFI) is the SG inlet flow restrictor. Other components with potential leakage flow paths include the joint between the upper and lower risers, gaps in and around the CRAGTs, and the gaps between the CRD shaft and ICIGT and the support plate holes. Provide quantitative explanations of how these regions, and any other RVI with potential leakage flow paths, are not susceptible to LFI. Include estimated pressure differences, along with quantitative explanations of how design rules for LFI avoidance (include applicable references) were followed. Provide a summary of the existing test results for the SG inlet flow restrictor, along with the test plan and acceptance criteria for testing of the final SG inlet flow restrictor design. Alternatively, NuScale may propose other options to resolve the staff's concerns.

Update the comprehensive vibration assessment program report TR-0716-50439 to include a summary of the requested information.

03.09.02-77

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. Given the uncertainties and potential non-conservatisms regarding the CRAGT FIV analyses and potential significant degradation, low margin against VS lock-in for ICIGT, CRDS, and SG tubes, low margin against FEI of SG tubes, and lack of LFI analyses or testing of RVI (with the exception of the SG inlet flow restrictors), provide an updated initial startup testing plan which includes instrumentation and test conditions to confirm the long-term integrity of those components. Also provide pre-test predictions of responses at instrumentation locations and acceptance criteria.

DCD Tier 2, Table 5.2-7 provides the long-term in-service inspection (ISI) method for RVI components such as the ICIGTs, and CRAGTs. Typically the components in the ISI program are inspected at the end of the 10-year interval. The components identified in the CVAP as susceptible to FIV may need more frequent inspections to identify abnormal wear early. It is unclear to the staff whether these components will have additional inspections prior to the end of the 10-year ISI program interval. Finally, summarize or provide the DCD sections that discusses the long term inspection plan for the CRD shafts and SG inlet flow restrictors. Alternatively, NuScale may propose other options to resolve the staff's concerns

Update the comprehensive vibration assessment program report TR-0716-50439 or the measurement and inspection plan to include the requested information.