February 08, 2019

Docket No. 52-048

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

SUBJECT: NuScale Power, LLC 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

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

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

- 03.09.02-76

The response to question 03.09.02-75 was submitted by Reference 2. The response to questions 03.09.02-73, 3.09.02-74, and 03.09.02-77 will be provided at a later date.

Enclosure 1 is the proprietary version of the NuScale 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 Response to NRC Request for Additional Information eRAI No. 9408, proprietary

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

Enclosure 3: Affidavit of Zackary W. Rad, AF-0219-64486

Enclosure 1:

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

Enclosure 2:

NuScale 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.: 03.09.02-76

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.

NuScale Response:

Quantitative screening criteria have been developed to determine whether further leakage flow instability (LFI) evaluation is required for components that are similar in geometry to those where LFI is encountered. These locations within the NuScale reactor module are primarily characterized by an annular flow channel with parallel walls, that can be approximated using a one-dimensional (1-D) analysis.

The steam generator inlet flow restrictor (SG IFR) and the riser slip joint are evaluated using alternate approaches.

References [1] and [2] define a methodology for evaluating the hydrodynamic added mass, damping, and stiffness due to the fluid dynamic forces caused by the coupled motion of the walls of a tapered passage. Theoretical values obtained using the methodology of References [1] and [2] correspond well to those obtained from validation experiments (Reference [3]). As a result, the methodology of Reference [2] is a valid approximation to quantitatively assess the potential for LFI at annular passages adjacent to beam or tube type structures such as the control rod assembly guide tube (CRAGT), in-core instrument guide tube (ICIGT), control rod drive (CRD) shaft sleeve, and CRD shaft supports. The methodology is applied to the leakage paths at the CRAGT, ICIGT, control rod drive shaft sleeve, and CRDS supports. For all locations, the inlet gap velocity is much less than the calculated critical velocity for LFI, indicating that LFI is not a concern; therefore, no additional testing or analyses are recommended for these components. A detailed summary of the screening, including pressure differences, has been added in Section 2.3.7 of the NuScale Comprehensive Vibration Assessment Program technical report, TR-0716-50439.

The one-dimensional annular flow channel methodology was not applied to the SG IFR. The pressure drop along the annular flow channel for this component is {{ }}2(a),(c) psi at full power, more than an order of magnitude larger than the maximum pressure difference for the remainder of the narrow flow channels. The annular gap around the SG IFR is {{ }}2(a),(c),ECI in., significantly smaller than the gaps in the other narrow flow channels discussed above. During normal operation, the gap velocity around the SG IFR is {{ }}2(a),(c) which far exceeds the other gap velocities. Accordingly, benchmarking and a separate effects test are performed to validate that LFI is not a concern for the SG IFR. The NuScale Comprehensive Vibration Assessment Program Measurement and Inspection Plan Technical Report, TR-0918-60894, Revision 0, submitted by NuScale letter LO-1218-63700, dated December 7, 2018, summarizes the plan for validation testing of the SG IFR final design in Section 5.3. Section 3.1 of TR-0918-60894 provides a summary of the existing test results for the SG IFR. The SG IFR is also included in the CVAP inspection program (see Section 7.0 of TR-0918-60894, Revision 0).

The riser slip joint consists of inner and outer conical shells creating a tapered annular gap ending at a load-bearing contact surface between the upper and lower risers that is approximately {{ }}2(a),(c),ECI wide around the circumference. Leakage flow instability at the riser slip joint is not plausible because the slip joint is maintained in a closed state by the downforce of the bellows in the upper riser and the weight of the upper riser transition, it has a

convergent flow passage, and the slip joint pressure difference is small: approximately {{ }}[2(a),(c)] psi. An evaluation of the hold-down force on the upper riser transition versus lifting force from differential pressure and bouyancy was performed, demonstrating a minimum hold-down force of {{ }}[2(a),(c)] lbf compared to a lifting force of {{ }}[2(a),(c)] lbf. The actual hold-down force during operation is higher after thermal expansion of the riser further compresses the upper riser bellows {{ }}[2(a),(c)]. LFI is not expected at this passage because fluid forces at the slip joint that act to open the leak channel are lower than the opposing forces of deadweight and upper riser bellows compression. Furthermore, vibration monitoring during initial startup testing will be provided for the slip joint (see Section 6.0 of TR-0918-60894, Revision 0), and the mating surfaces comprising the riser slip joint are included in the CVAP inspection program (see Section 7.0 of TR-0918-60894, Revision 0).

References

[1] Inada, F., "A Study on Leakage Flow Induced Vibration From Engineering Viewpoint," PVP2015-45944, *ASME 2015 Pressure Vessels and Piping Conference Volume 4: Fluid-Structure Interaction*, July 19-23, 2015, American Society of Mechanical Engineers, New York, 2015.

[2] Inada, F. and S. Hayama, "A Study on Leakage-Flow-Induced Vibrations. Part 1: Fluid-Dynamic Forces and Moments Acting on the Walls of a Narrow Tapered Passage," *Journal of Fluids and Structures,* (1990): 4:395-412.

[3] Inada, F. and S. Hayama, "A Study on Leakage-Flow-Induced Vibrations. Part 2: Stability Analysis and Experiments for Two-Degree-Of-Freedom Systems Combining Translational and Rotational Motions," *Journal of Fluids and Structures*, (1990): 4:413-428.

Impact on DCA:

The CVAP Technical Report TR-0716-50439 has been revised as described in the response above and as shown in the markup provided with this response.

The following subsections discuss in more detail the components that are screened for FIV and the components that are found to be susceptible to FIV based on the screening criteria. Components that are classified as susceptible to FIV require analysis, measurement, and inspection to meet the intent of the CVAP. Flow-induced vibration mechanisms and screening criteria, which are derived from References 8.1.3 and 8.1.4, are summarized in Table 2-3.

Table 2-2 NuScale Power Module components screened for susceptibility to flow induced vibration mechanisms

NPM Region or Category	Component	Section Number
Components exposed to secondary coolant flow	Steam piping, nozzle, MSIVs	2.3.1.1
	SG steam plenum Note 1	2.3.1.2
	DHRS steam piping	2.3.1.3
	DHRS condensate piping	2.3.1.3
	Helical SG tubing Note 1	2.3.1.4
	SG tube inlet flow restrictors	2.3.1.5
SG tube supports exposed to primary coolant flow	SG tube support bars	2.3.2.1
	SG lower tube support cantilevers	2.3.2.2
Upper riser assembly exposed to primary coolant flow	Upper riser section	2.3.3.1
	Riser section slip joint	2.3.3.2
	In-core instrument guide tube (ICIGT)	2.3.3.3, 2.3.7
	Control rod drive (CRD) shaft	2.3.3.4, 2.3.7
	CRD shaft support	2.3.3.5
	Upper riser hanger brace	2.3.3.6
	CRD shaft sleeve	2.3.7
Lower riser assembly exposed to primary coolant flow	Lower riser section	2.3.4.1
	Control rod assembly guide tube (CRAGT) assembly	2.3.4.2, 2.3.7
	CRAGT support plate	2.3.4.3
	Upper core plate	2.3.4.4
Core support assembly exposed to primary coolant flow	Core barrel	2.3.5.1
	Upper support block	2.3.5.2
	Core support block	2.3.5.3
	Belleville spring	2.3.5.4
	Reflector block	2.3.5.5
	Lower core plate	2.3.5.6
	Fuel pin interface	2.3.5.7
Other RVI exposed to primary coolant flow	Pressurizer spray RVI	2.3.6.1
	Chemical and volume control system (CVCS) injection RVI	2.3.6.2
	Flow diverter	2.3.6.3
	Thermowells Note 2	2.3.6.4
	Component and instrument ports	2.3.6.5

Notes to Table 2-2:

1. Component is exposed to primary and secondary coolant flow.

2. Thermowells also evaluated in NPM piping exposed to secondary coolant flow.

Table 2-3 Flow-induced vibration screening criteria

Phenomenon	Screening Criteria
Fluid elastic instability (FEI)	• array of cylinders (minimum one row), i.e., geometry • array pitch/diameter < 2.0; array must sufficiently confine fluid to allow feedback between adjacent cylinders
Vortex shedding (VS)	• bluff body (or edge of a cavity in line with flow) , i.e., geometry • subject to cross-flow • absence of downstream structures to disrupt vortices
Turbulent buffeting (TB)	• subject to turbulent flow (axial, cross-flow or combination) • component interface that is in load path of one or more components subject to turbulent flow
Acoustic resonance (AR)	• suitable geometry to generate an AR, typically a hollow or cavity • single phase environment within hollow/cavity
Leakage flow instability (LFI)	~~• narrow annular flow path exists, i.e., geometry~~ ~~• flexible structure in annulus, bounded by fixed surface~~ ~~• annular flow path is diverging (restriction at inlet to annulus) or parallel~~ ~~• flow conditions to generate sufficient flow velocity and pressure differential through annular flow path~~ Conditions 1 and 2 are met: 1. narrow annular flow path exists, i.e., geometry 2. flexible structure in annulus, bounded by fixed surface AND either Condition 3 or Condition 4 is satisfied: 3. flow conditions to generate sufficient flow velocity and pressure differential through annular flow path 4. annular flow velocity greater than the critical flow velocity for LFI (see Section 2.3.7)
Galloping/flutter	• non-circular cross section, i.e., geometry • aspect ratio (length/width) in prevailing direction of flow is less than 4.0 (for tall rectangular structure) and less than 2.0 (for low, long rectangular structure)

2.3.1 Components Exposed to Secondary Flow

The components exposed to secondary flow are contained in the SGS and DHRS. The SGS transfers heat from the reactor coolant to produce superheated steam, while

2.3.1.5 Steam Generator Tube Inlet Flow Restrictors

Each individual SG tube requires an inlet flow restriction device for the purpose of flow stability. Figure 2-8 provides a representation of the flow restrictor concept. The flow restrictor fits into the tube inlet and is designed to provide flow stability by restricting the volume of the secondary-side flow through the tube. The flow restriction is created by a series of narrow annular gaps between the restrictor and the tube inner diameter.To hold the flow restrictors in position, mounting hardware (plate) is required within the feed plenum. The plate is removable and held in place with fasteners. The flow restrictors are attached to this mounting plate. The flow restrictors and mounting hardware are anchored at a series of points with individual fasteners rather than with extended seams (e.g., welds). Based on the narrow annular gaps between the SG tube and the flow restrictor and the relatively large pressure loss in this region (Table 2-4), the flow restrictor is susceptible to leakage flow induced vibration. The mounting plate is stiffer than the flow restrictor and provides larger flow area. Therefore, leakage flow induced vibration is not a concern for the mounting plate. Similarly, the turbulent buffeting vibrations of the flow restrictor will bound those of the mounting plate due to the increased stiffness and reduced convective velocity of the mounting plate compared to the flow restrictor.

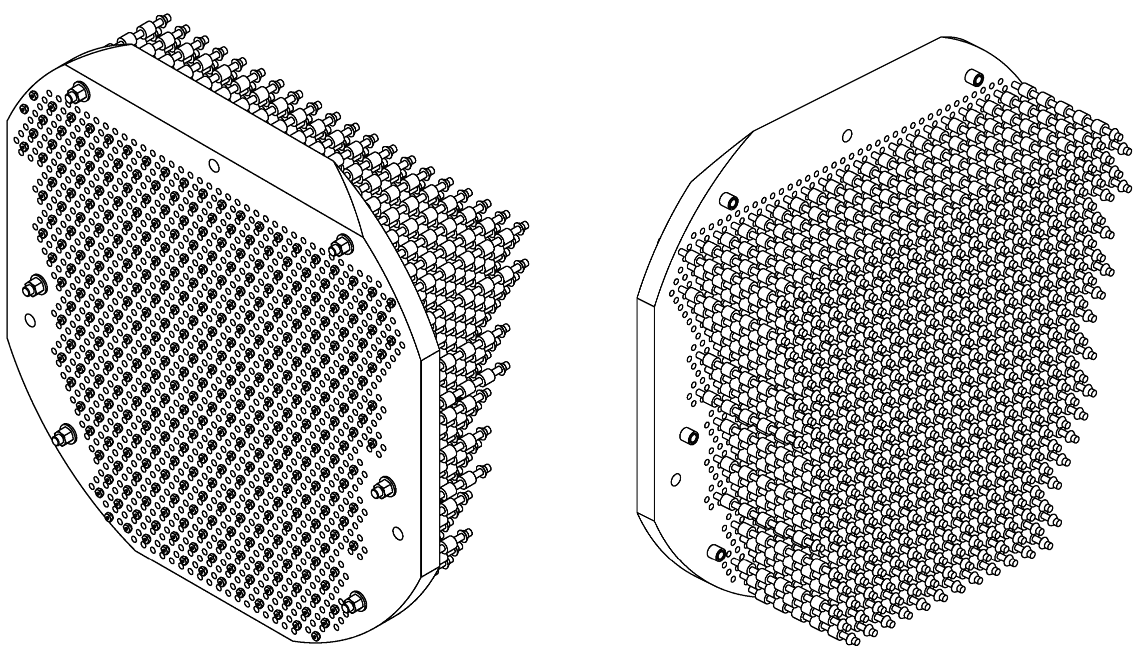

Figure 2-8 Tube inlet flow restrictor and mounting plate

2.3.3.2 Riser Section Slip Joint

A friction fit joint is located at the junction between the upper riser assembly and the lower riser assembly as shown in Figure 2-14. {{ }}2(a),(c),ECI At cold conditions the hold-down force on the joint from the bellows installed in the upper riser assembly plus deadweight of the bellows and upper riser transition is approximately {{ }}2(a),(c) lbf. The force is higher at operating conditions when thermal expansion further compresses the bellows {{ }}2(a),(c) {{ }}2(a),(c),ECI. This region does not screen for LFI because of the large hold-down force and the very small pressure difference of {{ }}2(a),(c) psi (Table 2-4) between the hot and cold legs of the primary coolant loop due to the natural circulation primary coolant flow. The lifting force on the upper riser transition from buoyancy and the pressure difference is approximately {{ }}2(a),(c) lbf. Therefore, LFI is screened out because fluid forces at the slip joint that act to open the leak channel are much lower than the opposing forces of deadweight and upper riser bellows compression. The slip joint itself is not susceptible to FEI, AR, gallop, or flutter as it is an open cylinder. The slip joint directs the fluid flow and does not cross the flow path, precluding it from VS susceptibility. The portions of the slip joint in contact with the hot and cold legs are susceptible to TB based on the flow conditions.

2.3.3.3 In-core Instrument Guide Tube

The ICIGTs extend from the upper RPV head to the top of the fuel assemblies. On the interior of the ICIGTs reside the in-core instruments which are routed through the pressure boundary at the RPV head and down into the core. The ICIGTs interface with the upper RPV head, pressurizer baffle plate, upper riser hanger ring, CRD shaft supports, lower riser assembly ICIGT support, and the upper core plate~~, and the in-core instruments~~. Each ICIGT is divided into three regions: tube sections within the pressurizer, upper riser, and lower riser. Each tube section is welded to at least one support location which fixes tube translation and rotation. ~~These~~The remainder of the ICIGT support interfaces provide lateral support while allowing small vertical displacements to accommodate differential thermal expansion movement.

~~On the interior of the ICIGTs reside the in-core instruments that are routed through the pressure boundary at the RPV head and down into the core. The clearance between the ICIGT and the CRD shaft support is negligible compared to the riser flow area. Additionally, due to the very low pressure differential across the supports, it is not credible that significant flow through this annulus will develop to create leakage flow instability.~~

~~During steady state operation, there is negligible pressure difference between the riser outlet and the pressurizer. Due to the momentum of the flow as it exits the riser, it is possible that some flow will pass through the annular flow regions between the ICIGT and CRD shaft and the pressurizer baffle plate. This flow is expected to be very low, based on the low driving force.~~

The geometry of the ICIGTs is constructed in a manner that they are not susceptible to FEI, acoustic resonance, gallop, or flutter. Although small gaps exist between the ICIGTs and ~~the~~CRD shaft supports and the lower ICIGT support, ~~the pressure drop and flow in these gaps~~screening evaluations show that the gap velocity is negligible ~~under all operating conditions~~compared to the critical velocity for leakage flow instability; therefore, LFI is not credible (Section 2.3.7). The ICIGTs are exposed to turbulent flow and are susceptible to TB. Above the upper riser section and below the pressurizer baffle plate, the ICIGTs are subject to crossflow; therefore, VS is also applicable for this component.

2.3.3.4 Control Rod Drive Shaft

The CRD shafts pass through the CRD shaft supports as they are routed to the fuel assemblies. The CRD shaft support openings are one of the CRD shaft alignment features and the clearance between the two components is small. Similar to the ICIGT, although the clearance between the component and support is small, the ~~pressure drop and~~gap velocity ~~are~~is sufficiently low compared to the critical velocity that LFI is not credible (Section 2.3.7). The CRD shafts also pass through the pressurizer baffle plate. During steady state operation, there is negligible pressure difference between the riser outlet and the pressurizer. Due to the momentum of the flow as it exits the riser, it is possible that some flow passes through the annular flow regions between the CRD shaft and the pressurizer baffle plate. This flow is expected to be very low, based on the low

driving force. Leakage flow instability screening for the CRD shaft interface with the pressurizer baffle plate and upper riser hanger ring has determined that the interface is not susceptible to LFI, as shown in Section 2.3.7.

Above the uppermost CRD shaft support, the fluid changes direction as it turns to the SG tube region. The CRD shaft becomes a bluff body with respect to the flow direction and is susceptible to VS in this region. Using the screening criteria, this interface is not susceptible to the FIV phenomena other than VS and TB.

2.3.3.5 Control Rod Drive Shaft Support

The CRD shaft support is attached to the upper riser section and is normal to the flow direction, as shown in Figure 2-15. As the primary fluid moves around the support beams, VS and TB may occur. Using the screening criteria, this component is not susceptible to the other FIV mechanisms.

support plate to the lower core plate. It also separates the up-flowing fluid above the core from the down-flowing fluid in the downcomer. The lower riser section is susceptible to TB due to parallel flow and vortices generated by the feed plenums. The open cylindrical shape precludes the lower riser section from being susceptible to FEI, AR, leakage flow, gallop, or flutter. The lower riser section is not susceptible to VS because no part of the component is opposing the flow path. Therefore, the lower riser section is only susceptible to TB.

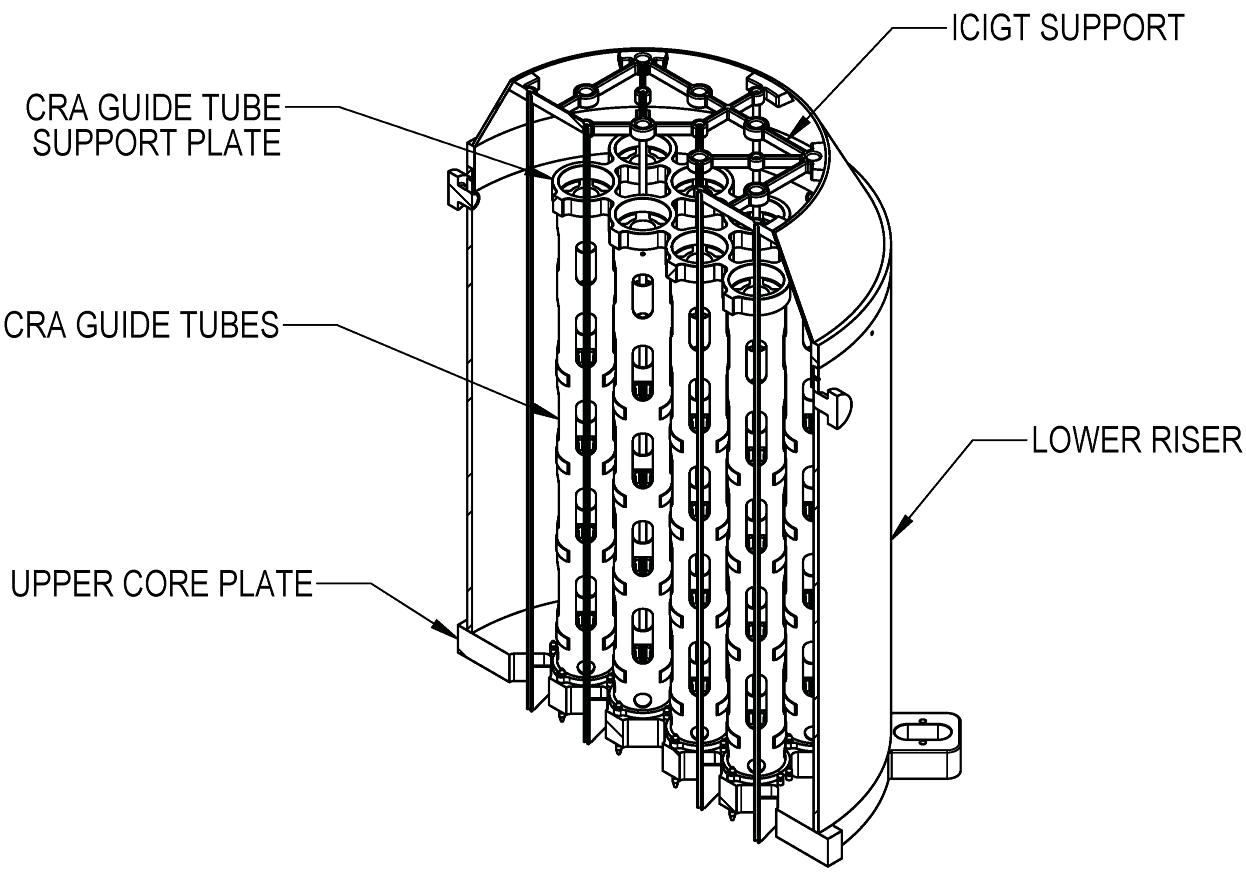

Figure 2-17 Lower riser assembly

2.3.4.2 Control Rod Assembly Guide Tube Assembly

The CRAGT supports the CRAs at varying amounts of control rod insertion, as shown in Figure 2-18. The CRAGT assembly includes four CRA cards, the CRA lower flange, the CRA guide tube, and the CRA alignment cone. The CRA cards, lower flange, and alignment cone are welded to the CRAGT guide tube to form the CRAGT assembly. The CRAGT assemblies are supported by the upper core plate and the guide tube support plate (Section 2.3.4.3).

The CRAGT components have many sharp edges to cause VS and TB. The CRAGT assembly is not susceptible to leakage flow because the annular gap velocity at the

CRAGT support, driven by a small pressure difference, is well below the critical velocity that screens this component for LFI.there is not an annular flow path with a flexible boundary. There is no cavity region in the CRAGT assembly where AR could form. The CRAGT assembly is designed to allow flow to pass in and out of the guide tube. There are no flow-occluded regions and any vortices that form are dissipated by the turbulent flow. Using the screening criteria, the CRAGT is not susceptible to the FIV phenomena, other than VS and TB.

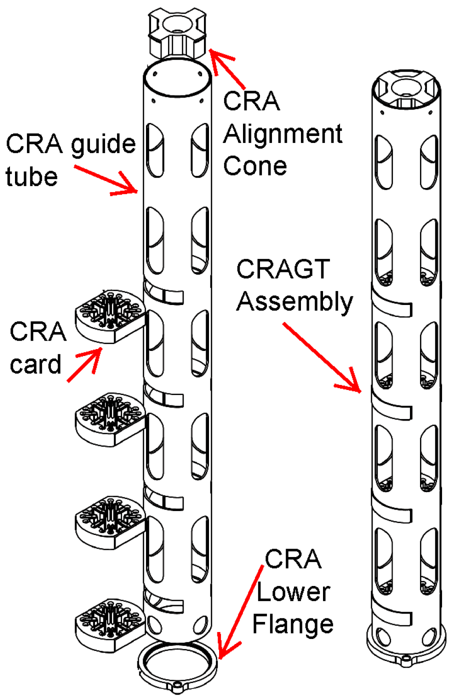

Figure 2-18 Control rod assembly guide tube assembly

2.3.4.3 Control Rod Assembly Guide Tube Support Plate

The CRAGT support plates are located above the CRAGT assembly, as depicted in Figure 2-17. Similar to the CRAGT assembly, the support plate is subject to turbulent flow and also represents a bluff body subject to cross flow. Further, there is no cavity region downstream of the CRAGT support plate where AR could form. As shown in Figure 2-15, the downstream region contains the control rod drive shaft, control rod drive shaft supports and ICIGT. Therefore, TB and VS are applicable mechanisms. Other mechanisms are not considered credible.

2.3.4.4 Upper Core Plate

The upper core plate functions in conjunction with the core support assembly to align and support the reactor core system. The upper core plate is welded to the bottom of the lower riser, as depicted in Figure 2-17. Four lock plate assemblies align the lower riser

the valve is open (See Figure 2-25). The valve disc is not in direct cross flow, and downstream structures (the valve 90 degree turn) are present to disrupt any potential vortices generated by the valve internals. The valve body is designed for reaction loads of valve discharge and seismic loads, and is therefore thick-walled relative to schedule 160 piping. It is not a bounding component for turbulent buffeting analysis (Section 3.2.3). Due to the geometry in the ECCS valves, no FIV mechanisms are credible for through-valve flow.

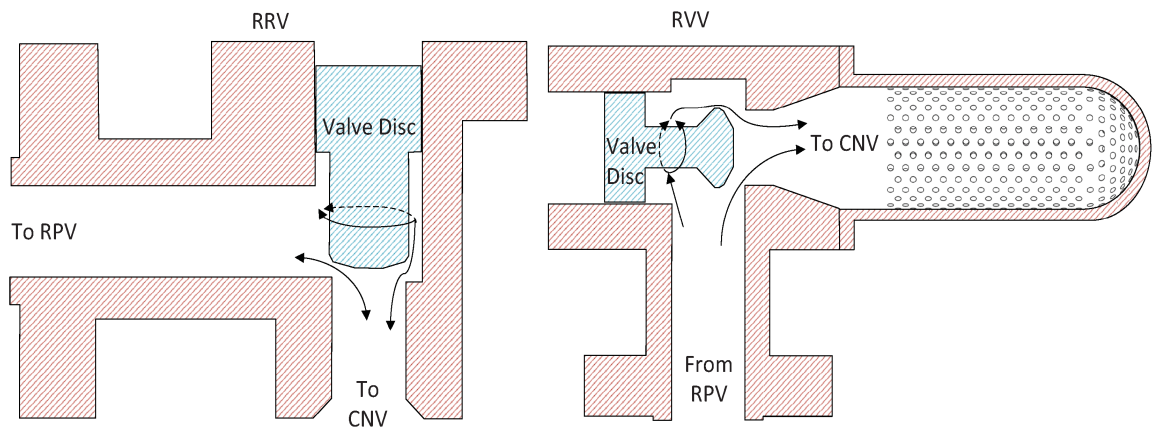

Figure 2-25 ECCS Valve Internal Flow Diagram

2.3.7 Leakage Flow Instability Screening Using Critical Gap Velocity

References 8.1.15 and 8.1.16 define a methodology for evaluating the hydrodynamic added mass, damping, and stiffness due to the fluid dynamic forces caused by the coupled motion of the walls of a tapered passage. Reference 8.1.16 applies to a tapered one-dimensional passage coupled to walls with one rotational and one translational degree of freedom. Reference 8.1.15 applies to a tapered annular passage with a wall having a single translational degree of freedom. Theoretical values obtained using the methodology of References 8.1.15 and 8.1.16 correspond well to those obtained from experiments (Reference 8.1.17). Therefore, the methodology of Reference 8.1.16 is a valid approximation to quantitatively assess the potential for LFI at annular passages adjacent to beam or tube type structures such as the CRAGT, ICIGT, CRD shaft sleeve, and CRD shaft supports.

Critical velocity evaluations are performed to screen reactor vessel internals components 1 – 10 in Table 2-4. The pressure differences shown in Table 2-4 are estimated from CFD analyses and loss coefficients used in the reactor coolant system thermal-hydraulic model. The inlet gap velocity is calculated using a formula from Reference 8.1.18 and the critical gap velocity is calculated using a methodology from References 8.1.15 and 8.1.16.

In Table 2-4, the critical velocity is defined as the velocity at which the hydrodynamic damping (with zero structural damping included) becomes negative. If positive structural damping is added to hydrodynamic damping, the critical flow velocity is higher.

It is noted that the annular gaps surrounding the CRD shaft, CRD shaft sleeve, ICIGT, and CRAGT are of uniform width, i.e., none are tapered. Nonetheless, the critical flow velocity shown in Table 2-4 for these components is calculated assuming an exit annular gap 25% greater than the inlet annular gap, which is less stable and thus more conservative.

Table 2-4 Reactor vessel internals components screened for LFI

Reactor Module Components			Pressure Difference (psi)	Inlet Gap Velocity (in/sec)	Critical Gap Velocity in/sec	Notes
#	Interior	Exterior				
1	CRD shaft	CRD shaft supports within riser	{{			upflow
2	CRD shaft	top CRD shaft support				upflow
						downflow
3	CRD shaft sleeve	top CRD shaft support				upflow
4	CRD shaft	CRD shaft sleeve				upflow
						downflow
5	CRD shaft	pressurizer baffle plate				upflow
						downflow
6	CRD shaft	upper riser hanger ring				upflow
						downflow
7	ICIGT	ICIGT supports within riser				upflow
8	ICIGT	lower ICIGT support				upflow
9	CRAGT	CRAGT support plate				upflow
10	CRD shaft	CRD shaft alignment cone			}}2(a),(c)	upflow
11	upper riser assembly at slip joint	lower riser assembly at slip joint	{{ }}2(a),(c)	Slip joint is maintained in a closed condition (Section 2.3.3.2).		
12	SG inlet flow restrictor	SG tube	{{ }}2(a),(c)	A separate effects test is performed to validate that LFI is not a concern (Sections 2.3.1.5 and 4.1.1).		

Note(s) for Table 2-4:

1. This velocity is calculated based on a pressure drop for inflow to the pressurizer during a reactor safety valve actuation, which is bounding. Gap velocities during normal steady-state operation are significantly lower (Section 2.3.3.4)

The screening evaluations indicate that LFI is not a concern for the leakage paths around the control rod drive shaft, ICIGT, CRAGT, and control rod drive shaft sleeve. The calculated critical velocity for LFI exceeds the actual gap velocity in each instance. No additional testing or analyses are recommended for these components. The riser slip joint and SG inlet flow restrictor are screened using alternate approaches as discussed in the sections cited in Table 2-4.

2.4 Regulatory Requirements

Consistent with RG 1.20, Section 2, the prototype CVAP for the NPM is composed of three sub-programs. The program includes

- a vibration and stress analysis program
- a vibration measurement program
- an inspection program

The analysis program uses theoretical analysis to predict the natural frequencies, mode shapes, and structural responses of the NPM components to various sources of flow excitations.

The measurement program consists of prototype testing that is used to validate the analysis program inputs, results, and margins of safety. Prototype testing consists of separate effects, factory, and initial startup tests. The measurement program verifies the structural integrity of the NPM components. If discrepancies are identified between the analysis and the measurement programs, reconciliation is performed.

The inspection program consists of inspections of the applicable NPM components before and after initial startup testing in order to confirm that the vibratory behavior of the susceptible components is acceptable. Inspection is generally performed outside the NPM, but if the components are not separable, then an in situ inspection process can be specified. Inspections consist of visual examinations.

To finalize the CVAP, two additional technical reports are developed. The first report contains the measurement program details for each prototype test, including test operating conditions, test durations, instrument types and locations, applicable testing hold points, and pre-test predictions of the expected and allowable experimental results, considering bias errors and random uncertainties. The second report provides the post-test evaluation of the testing completed to support the measurement program. In this report, the differences between the expected and measured experimental results are dispositioned and all results are confirmed to be in the analytically predicted allowable ranges. The second report also documents the inspection program results.

2.5 Classification of NuScale Power Module

Regulatory Guide 1.20 provides guidance to verify the structural integrity of the NPM internals susceptible to FIV. The verification measures depend upon the classification of the internals.

Table 3-4 Flow conditions input summary

Analysis Category	Assumed Conditions	Analysis Method
FEI	Maximum design flow – average velocity	CFD Note 1
VS	Maximum design flow – average velocity	CFD Note 1
	Design flow at 102% – average velocity assuming low SG superheat performance	TH Note 4
AR	Maximum design flow – average velocity	CFD
	Design flow at 102% – average velocity assuming low SG superheat performance	TH Note 4
F/G	Maximum design flow – average velocity	CFD
LFI	None Note 2	None
TB	Maximum design flow – average or maximum velocity Note 3	CFD

Note(s) for Table 3-4:

1. For the VS and FEI analysis of the SG tubes, CFD flow rate is modified to represent velocity in the minimum flow area.
2. LFI confirmation is by prototype testing only for components that are screened as potentially susceptible to LFI.
3. Either average or maximum velocities are chosen for each component in TB analysis based on achieving the most bounding convective velocity for the purpose of impact and fatigue evaluations.
4. For the evaluation of AR and VS mechanisms for components exposed to secondary coolant flows, the TH flow is used. CFD analysis is not performed to characterize secondary side flow.

Table 3-5 lists velocities used in the analyses of components subject to FIVrepresentative average velocities based on CFD analysis at the maximum design flow. The analysis methods that produce these velocitiescategories and components that use the CFD results are identified in Table 3-4, except as noted otherwise below.

Table 3-5 Maximum design flow velocities based on CFD

Flow Region	Average Velocity (in/s)
Around/Through CRAGTs	{{ }}2(b),(c),ECI
CRAGT Support	{{ }}2(b),(c),ECI
Bottom of Conic Riser Transition	{{ }}2(b),(c),ECI
CRD Shaft Support	{{ }}2(b),(c),ECI
Upper Riser	{{ }}2(b),(c),ECI
Flow Over the Top of the Upper Riser	{{ }}2(b),(c),ECI
Top of Conic Downcomer Transition	{{ }}2(b),(c),ECI
Bottom of Conic Downcomer Transition	{{ }}2(b),(c),ECI
Downcomer, around Core Barrel	{{ }}2(b),(c),ECI

Table 3-5 Velocities used in FIV analyses

Analysis Category	Component	Velocity (in/s)
FEI Note 1	Helical SG tubing	{{
VS Note 1	Helical SG tubing	
	SG tube support cantilever	
	RCS hot region thermowell	
	RCS cold region thermowell	
	CNTS steam thermowell	
	CNTS feedwater thermowell	
	Control rod drive shafts	
	CRD shaft support	
	Control rod assembly guide tubes	
	CRAGT support	
	Upper riser hanger brace	
	CVCS Injection RVI (in downcomer)	
	In-core instrument guide tubes	
AR Note 4	DHRS steam line tee	
	DHRS condensate line tee	
	Reactor recirculation valve nozzle	
	Flowmeter port	
F/G Note 1	SG tube support cantilever	}}2(b),(c),ECI
LFI	None, LFI confirmation is by prototype testing only for components that are screened as potentially susceptible to LFI.	
TB	Helical SG tubing, primary flow	{{
	Helical SG tubing, secondary flow (steam)	
	Helical SG tubing, secondary flow (liquid)	
	SG inlet flow restrictor	
	Core barrel	
	CRAGT inner diameter	
	CRAGT outer diameter	
	CRAGT support	
	CRD shaft	
	CRD shaft support	}}2(b),(c),ECI

Analysis Category	Component	Velocity (in/s)
	Flow diverter	{{
	Lower ICIGT	
	Upper ICIGT	
	Injection line, downcomer	
	Injection line, downcomer, interior	
	Lower core plate	
	Lower riser inner diameter	
	Lower riser outer diameter	
	Upper core plate	
	Upper riser inner diameter	
	Upper riser outer diameter	}}2(b),(c),ECI

Notes for Table 3-5:

1. {{ }}2(b),(c),ECI margin is included in these values for transient velocity changes
2. Primary side gap velocity based on a minimum cross-sectional flow area
3. Component of this velocity perpendicular to the tubes is used in the analysis
4. {{ }}2(b),(c),ECI is added to these values in the analysis to account for transient velocity changes
5. Velocity is from TH analysis
6. Velocity is hand-calculated

3.1.3 Damping Ratios

Damping can be created from various sources, such as material, fluid viscosity, or structural interactions. Damping reduces a structural response. The damping ratios for structures have historically been determined through testing. ASME Boiler and Pressure Vessel Code, Appendix N-1300 (Reference 8.1.2) provides recommendations for damping ratios of SG tubes.

- Analysis for FEI of SG tubes: damping due to viscous effects of the primary fluid is not credited. Damping created by other sources (material and structural interaction) is expected to be 1.5 percent based on the guidance in Paragraph N-1331.3 of Appendix N. The damping ratio has a significant influence on the stability ratio that is compared to the acceptance criteria, which represents the margin to the onset of FEI for the SG tubes. Additionally, RG 1.20 states that any attempt to specify structural damping coefficients greater than 1 percent for frequencies greater than seismic frequencies should be supported by experimental measurements. Therefore, prototype testing is required to confirm that the damping ratio of 1.5% that is credited in the FEI analysis for the SG tube is appropriate.
- Analysis for VS of SG tubes: a damping ratio of 1.5 percent is used, consistent with the damping ratio used for FEI analysis. Prototype testing is required to confirm the damping ratio of 1.5% that is credited in the VS analysis for the SG tube is appropriate.
- Analysis for TB and vortex shedding of ICIGT: a damping ratio of 0.5 percent is used for the SG Alloy 690 tubes and the stainless steel type 304 ICIGT and 0.3 percent is used for all other RVI stainless steel structures. These damping ratios are representative of hysteresis (material damping) and are less than 1%. They conservatively neglect damping due to structural interactions and viscosity. Compared with the FEI and VS analyses, a smaller damping ratio is assumed for the SG tubes because lower amplitudes of vibration with less tube-to-tube support interactions are expected with this source of flow excitation. This guidance is consistent with Appendix N-1300. Because the damping values used in TB and vortex shedding analysis of the ICIGTs are based only on material damping and are less than 1%, they are considered to be sufficiently bounding. It is not credible that this input could have a non-conservative effect on the calculated margin of safety. Therefore, testing is not required to verify the damping values used in TB analyses or VS analysis of the ICIGT.
- Analysis for LFI: because components undergo prototype testing if the possibility of LFI is indicated by screening evaluations~~there are no industry-accepted practices for analytically predicting LFI~~, further analysis is not recommended and a damping value is not provided.

As summarized in Table 3-6, the only damping values that require verification are the SG tube damping values used in the VS and FEI analyses. The basis for verifying these analytical inputs is the margin of safety, as identified in Sections 3.2.1, 3.2.2, and 3.2.3.

bound of the Strouhal number range for susceptibility to AR. More than 100 percent margin is also demonstrated for the RRV cavity and instrument cavities in the RCS downcomer region. Testing is required to confirm that AR does not occur in the DHRS steam piping. Results and testing information are summarized in Table 3-11.

Table 3-11 Acoustic resonance results summary

Component	Safety Margin	Items to Verify	Verification Method and Testing Phase	Test
DHRS steam piping	{{ }}2(b),(c),ECI	Vibration amplitude	Initial startup testing	Flow testing (Section 4.3)

3.2.5 Leakage Flow Instability

~~Due to the sensitivity of LFI~~Leakage flow instability is sensitive to flow and geometry conditions.~~, there are no accepted analytical methods and acceptance criteria available to predict a critical velocity for the onset of LFI.~~ For NPM components that meet the screening criteria for LFI, testing is required to determine susceptibility to LFI.

The major parameters that have been shown to lead to LFI are large pressure differences across small annular gaps, component flexibility, and small diffusion angles. Due to the natural circulation design of the NPM, most regions are not susceptible to LFI because pressure differences across these interfaces, and thus gap velocities, are very small under all operating conditions. One exception to this is on the secondary coolant side at the entrance to the SG tubes, where a flow restrictor upstream of each SG tube is provided. The SG tube flow restrictor is designed to provide flow stability by restricting the volume of secondary side flow through the tube. The flow restriction is created by narrow annular gaps between the flow restrictor and the tube inner diameter. A separate effects test is performed to validate that LFI is not a concern for the SG tube flow restrictor, per Table 3-12.

Table 3-12 Leakage flow instability results summary

Component	Safety Margin	Items to Verify	Verification Method and Testing Phase	Test
SG tube inlet flow restrictors	Need to verify	Vibration amplitude	Separate effects testing	SG tube inlet flow restrictor test (Section 4.1.1)

3.2.6 Gallop and Flutter

The SG tube support cantilever is the only NPM structure that requires evaluation for flow excitation created by gallop and flutter.

Flow tests of rectangular cross sections have been performed to investigate the influence of the VS frequency and the response of the structure to torsional gallop considering both smooth and turbulent flow conditions. The results of the flow test summarized in Reference 8.1.5 are applicable to rectangular cross sections whose height-to-width ratio is between 0.2 and 5.0. For the SG cantilever support, this ratio is

validate relevant input parameters because they can be quantitatively used to sufficiently validate predicted analytical margin.

For VS analysis of all components except the SG tubes and ICIGTs, the key input that requires validation is the fundamental frequency. For the SG tubes, the frequencies, mode shapes, and damping ratio are relevant inputs for both VS and FEI analyses that affect the predicted analytical margin and require validation. For the ICIGTs, the frequencies and mode shapes require validation, but since a conservatively low damping value is used (0.5%) validation of that input is not necessary. For components that undergo flow testing, the dynamic pressure measurement results can be used to demonstrate if there are spectral peaks in the PSD that could be attributed to vortex shedding, acoustic resonance, and leakage flow instability. Additionally, dynamic pressure fluctuations created by AR inside the piping system may be measured using strain gages mounted on the pipe wall to detect this source of flow excitation.

Because components susceptible to TB experience vibration when exposed to turbulent flow, it is possible to validate the TB analysis during natural circulation operating conditions. The analysis of the NPM components for TB currently considers PSDs that have been published in open literature and used by the industry. Based upon the computed response of the NPM components considering these FIV inputs, components with less than a 100 percent margin of safety are selected for instrumentation and testing to verify the FIV inputs and analysis results for TB.

Pre-test predictions for all prototype tests that have an associated design analysis methodology are performed to ensure that the overall experiment design, including test conditions, number and location of sensors, and sensor accuracy are sufficient to validate the analysis program. Pre-test predictions provide the expected test result ranges considering uncertainties due to operating conditions, manufacturing tolerances, instrument error, and other sources of experimental biases and uncertainties. Pre-test predictions demonstrate the range of acceptable experimental results that can be used to validate analysis inputs, results, and margins of safety. Post-test analysis verifies the results fall within the pre-test prediction acceptable range, and justifies technically relevant differences between the predicted and actual test results.

Section 2.2 of RG 1.20 suggests that steam, feedwater and condensate piping should be instrumented for vibration measurement during initial startup testing. With the exception of the DHRS steam piping, these components either do not screen for FIV or have been shown to have a margin of safety greater than 100 percent. Only components with less than 100 percent safety margin are tested in the prototype measurement program, consistent with the overall measurement program objectives of validating relevant analytical inputs, results, and margins of safety.

Table 4-1 summarizes the testing and inspections to be performed to verify the FIV analysis program for the prototype NPM. The testing scope addresses five components:

- DHRS steam piping: Testing to validate the AR safety margin is performed during initial startup testing. See Section 4.3 for additional details.

SG tube inlet flow restrictor and SG tube bundle are performed. A summary of the testing scope and objectives are summarized in the following sections. The specific test details, such as operating conditions, test durations, instrument types and locations, applicable testing hold points, and pre-test predictions of the expected and allowable experimental results, considering bias errors and random uncertainties, will be provided in the CVAP Measurement Program Report.

4.1.1 Steam Generator Tube Inlet Flow Restrictor Test

This separate effects test provides an assessment of the vibration performance of the SG tube inlet flow restrictors. The test results are used to verify acceptable performance against LFI. Although verification for TB is not required because impact is not predicted to occur, the testing results may be used to verify TB analysis inputs and methods for this component, to the extent practical. This test is described further in Section 5.3 of the NuScale Comprehensive Vibration Assessment Program Measurement and Inspection Plan Technical Report (Reference 8.1.14).

~~Flow tests are performed at a range of flow rate conditions that cover limiting operating flow conditions. The tests are run at low temperature and pressure conditions. Corrections for these test conditions are performed analytically to demonstrate acceptable performance at full power operating conditions.~~

4.1.2 Steam Generator Flow Induced Vibration Test

The full-scale mockup of the SG tube bundle has five prototypic helical columns and supports. This separate effects test provides an assessment of the vibration performance of the SG tubes and tube supports to aid in demonstrating that FEI and VS are not active sources of flow excitation at the equivalent full-power normal operating conditions. The SG tube bundle testing may not achieve the TH conditions corresponding to the predicted onset of the FEI and VS phenomena. However, the testing will provide validation of analytical inputs such as frequency and mode shape. The damping ratio associated with the tube-to-tube support interaction with amplitudes of vibration equivalent to those at full-power normal operating conditions will also be determined with this test to allow the verification of this FIV input used in the analyses. The response of the tube bundle to flow excitation due to TB will be measured, as well as the primary-side flow PSD to verify this input and the analytical results for the tube.

The tests include in-air frequency measurements, in-water frequency measurements, and flow testing of the full-scale five column model.

The following simplifications are adapted into the design of the SG tube bundle mockup facility. While these represent deviations from full-power normal operating conditions, these differences are judged to either not affect the vibration results or corrections can be performed analytically to account for these differences.

- Because the objective of this test is to characterize FIV resulting from single-phase primary flow, testing with a fluid at room temperature is sufficient to define the modal frequencies, the damping ratio, and the PSDs. A correction to these FIV inputs to

8.1.14 NuScale Power, LLC, "NuScale Comprehensive Vibration Assessment Program Measurement and Inspection Plan Technical Report," TR-0918-60894-P.

8.1.15 Inada, F., "A Study on Leakage Flow Induced Vibration From Engineering Viewpoint," PVP2015-45944, ASME 2015 Pressure Vessels and Piping Conference Volume 4: Fluid-Structure Interaction, July 19–23, 2015, American Society of Mechanical Engineers, New York, NY, 2015.

8.1.16 Inada, F. and S. Hayama, "A Study on Leakage-Flow-Induced Vibrations. Part 1: Fluid-Dynamic Forces and Moments Acting on the Walls of a Narrow Tapered Passage," Journal of Fluids and Structures, (1990): 4:395-412.

8.1.17 Inada, F. and S. Hayama, "A Study on Leakage-Flow-Induced Vibrations. Part 2: Stability Analysis and Experiments for Two-Degree-Of-Freedom Systems Combining Translational and Rotational Motions," Journal of Fluids and Structures, (1990): 4:413-428.

8.1.18 Inada, F., "A Parameter Study of Leakage-Flow-Induced Vibrations," Proceedings of the ASME 2009 Pressure Vessels and Piping Division Conference, July 26-30, 2009, American Society of Mechanical Engineers, New York, NY, 2009.

Enclosure 3:

Affidavit of Zackary W. Rad, AF-0219-64486

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 comprehensive vibration assessment program.

    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 No. 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 February 8, 2019.

Zackary W. Rad