RAIO-0118-58326

January 26, 2018

Docket: PROJ0769

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

SUBJECT: NuScale Power, LLC Response to NRC Request for Additional Information No. 9105 (eRAI No. 9105) on the NuScale Topical Report, "Evaluation Methodology for Stability Analysis of the NuScale Power Module," TR-0516-49417, Revision 0

REFERENCES:
1. U.S. Nuclear Regulatory Commission, "Request for Additional Information No. 9105 (eRAI No. 9105)," dated September 22, 2017
2. NuScale Topical Report, "Evaluation Methodology for Stability Analysis of the NuScale Power Module," TR-0516-49417, Revision 0, dated July 2016

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. 9105:

- 01-48

Enclosure 1 is the proprietary version of the NuScale Response to NRC RAI No. 9105 (eRAI No. 9105). NuScale requests that the proprietary version be withheld from public disclosure in accordance with the requirements of 10 CFR § 2.390. 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 Darrell Gardner at 980-349-4829 or at dgardner@nuscalepower.com.

Sincerely,

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

Distribution: Gregory Cranston, NRC, OWFN-8G9A
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Enclosure 1: NuScale Response to NRC Request for Additional Information eRAI No. 9105, proprietary

Enclosure 2: NuScale Response to NRC Request for Additional Information eRAI No. 9105, nonproprietary

Enclosure 3: Affidavit of Zackary W. Rad, AF-0118-58327

Enclosure 1:

NuScale Response to NRC Request for Additional Information eRAI No. 9105, proprietary

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Enclosure 2:

NuScale Response to NRC Request for Additional Information eRAI No. 9105, nonproprietary

Response to Request for Additional Information

eRAI No.: 9105
Date of RAI Issue: 09/22/2017

NRC Question No.: 01-48

Title 10 of the Code of Federal Regulations (CFR), Part 50, Appendix A, General. Design Criterion (GDC) 10, “Reactor design,” states that the reactor core and associated coolant, control, and protection systems shall be designed with appropriate margin to assure that specified acceptable fuel design limits are not exceeded during any condition of normal operation, including the effects of anticipated operational occurrences. GDC12, "Suppression of reactor power oscillations," requires that oscillations be either not possible or reliably detected and suppressed. The Standard Review Plan (SRP) 15.0.2 acceptance criteria with respect to evaluation models specifies that the chosen mathematical models and the numerical solution of those models must be able to predict the important physical phenomena reasonably well from both qualitative and quantitative points of view.

Section 5.8, "Numerical Solution," of the topical report (TR), TR-0516-49417-P, discusses the overall numerical solution of PIM, and indicates that the "numerical arrangement {{ }}2(a),(c) produces numerically stable solutions while minimizing the numerical damping." As stated in section 5.1, "Background for Theory and Model Description of the PIM Code," of the TR, "PIM relies on the published description of the theory and numerical methods of RAMONA, but is not a direct derivative of the coding." Since PIM is developed independently of RAMONA, numerical damping behavior and issues should be addressed by verifying PIM predictions against relevant problems with analytical solutions.

In order to make an affirmative finding NRC staff requests NuScale to:

1. Provide verification of PIM against analytical solutions that exhibit undamped and damped oscillatory behavior.
2. Use the results of the verification to analyze numerical diffusion in PIM.

NuScale Response:

Item 1:

PIM, in this aspect is like RAMONA, and not a general system code but rather hardwired to the geometry of the NuScale design. The code structure is not capable of performing an oscillating manometer problem or isolated problems like simulating a damped harmonic oscillator or following cold slugs. Other code limitations apply, for example, a manometer oscillation requires reverse flow capability which is not programmed in PIM. However, the response to this RAI utilizes other means of addressing the intent of the requested analysis.

The concept of numerical diffusion needs to be addressed in transient numerical simulation of mass and energy transport. PIM applies a special explicit finite volume one-dimensional algorithm which is selected for minimizing numerical damping resulting from diffusion. The numerical problems are addressed as kinematic (diffusion) and dynamic (damping) aspects.

Kinematic Effects of Numerical Diffusion

Numerical diffusion has been studied using an idealized one-dimensional transport at constant velocity driven by a boundary forcing function at the inlet end of the pipe. The transported parameter, e.g. temperature, is studied over the length of the pipe particularly at the opposite end as time increases. See Reference 1 as an example. The ideal exact solution at any point within the pipe is the same as the boundary value at an earlier time where the time delay is equal to the time it takes the flow to travel from the boundary to that point. In this way, a step change in temperature at the boundary is transported as a traveling wave where the magnitude of the discontinuity is preserved (without diffusion). In a numerical solution where the pipe is divided into a finite number of segments, and time is discretized using finite time steps, partial derivatives of the transported parameter are approximated and result in truncation errors. The truncation errors in the numerical representation are equivalent to physical diffusion. Consequently, for the numerical solution, a step change of temperature at the inlet end of the pipe will diffuse as it travels through the pipe where the gradient of the temperature diminishes. The magnitude of the numerical diffusion generally decreases with increasing the number of the segments (nodes or cells) and depends on the solution algorithm. Solution algorithms vary in order (number of nodal values up- and down-stream of the solution location), and whether current or previous time step values are used in formulating the spatial derivatives. The simplest formulations are first order donor cell type (up-stream nodal value is used to approximate spatial derivatives) where the explicit form uses only the previous time step nodal values to approximate the spatial derivative, and the implicit form where the current time step is used instead. Characteristics of the explicit and implicit solutions are well known such that the explicit solution is less diffusive than the implicit solution. In the explicit solution, diffusion is eliminated with a Courant number of unity, where the Courant number is defined as the ratio of the distance traversed by the flow in a single time step relative to the length of a node. However, a Courant number of unity is at the edge of numerical instability for an explicit solution and numerical errors due to round off or any other source can accumulate. Also, non-diffusive solutions are not necessarily the best representation of the physical processes in real systems where, for example, the turbulence and heat exchange with pipe walls are physically diffusive processes. In practice, it is difficult to control the Courant number over time and space because simulations generally demand different node sizes for different parts of the system and the flow may accelerate resulting in different flow velocities in different parts of the system at different times. Also, the Courant number is not unique in the case of two-phase flow with interfacial slip. Consequently some amount of numerical diffusion is unavoidable, but can be addressed using best practices.

The above summary is an overview of the nuclear industry consensus as presented in the open literature. To investigate numerical diffusion in PIM, NuScale completed a study as it relates to density wave stability calculations. Evaluations were made between the explicit method and the implicit method in the solution of the flow transport equation. For this purpose, the model problem comprised a 1 meter horizontal pipe containing an adiabatic single phase flow at 1 m/sec, which sets up a dimensionless system applicable to any length and velocity. Two boundary conditions were tested. The first one is a sinusoidal oscillatory signal, and the second one is a step function. The results of this study are shown in Figure 1 through 7 where variations of nodalization and Courant number and the type of boundary perturbation are demonstrated for both the explicit and implicit integration schemes.

In the case of a sinusoidal oscillatory signal, the density wave kinematics is not arbitrary; rather the phase of a perturbation at the exit of a heated pipe is nearly 180 degrees lagging the inlet perturbation. Yet, due to diffusion, the amplitude of a sinusoidal perturbation at the inlet is attenuated as the perturbation travels up the pipe length. An important aspect of the density wave dynamics is that the driving force for flow change is the total density head, which is proportional to the integrated (sum in the case of finite volume numerical representation) density over the pipe length. Numerical diffusion as described by the kinematics causes the spread of the density (equivalently temperature) variations over the pipe length. The diffusive spread that lowers temperature at one node also increases it at another node. The density head error is the sum of these positive and negative errors which reduces the net error in the density head due to diffusion. This result is demonstrated in Figure 4 where the relative damping of a sinusoidal forcing function at the inlet of a pipe as it reaches the exit of the pipe is shown to be larger than the average value over the pipe length. The figure also shows the effect of the Courant number and the number of nodes used in the numerical solution. From Figure 4, it is concluded that the effect of numerical diffusion on the integrated temperature is small for Courant numbers greater than 0.5 and for large number of nodes greater than 40; both conditions are satisfied in PIM simulations for the NuScale design.

The results of these numerical calculations confirm that (1) the explicit scheme is less diffusive than the implicit scheme for the same nodalization and Courant number, (2) the explicit scheme is non-diffusive in the limit of Courant number of unity, (3) the extent of diffusion decreases with increasing Courant number for the explicit scheme while the opposite is true for the implicit scheme, and (4) both explicit and implicit scheme suffer less diffusion when the number of nodes is increased. The new aspect of the reduced attenuation for the average transported parameter compared with its exit value is also demonstrated for both the explicit and implicit schemes.

Dynamic Effects of Numerical Diffusion

The extent of diffusion as shown in a kinematic representation serves as a qualitative indicator of the dynamic effect but not a quantitative one. The dynamic effect manifests itself as a damped response, e.g. an underestimated decay ratio for a stability calculation. This qualitative relationship has been recognized in the nuclear industry with respect to BWR stability calculations and resulted in the preference of using explicit schemes. A more rigorous quantification of the dynamic effect of numerical diffusion is presented here using the NuScale reduced order model RADYA.

RADYA models a single-phase natural circulation loop where the length of each node is specified such that all nodes have the same volume. With the application of Boussinesq approximation (constant liquid density with the exception of the thermal expansion effect used for calculating density head), the continuity equation forces a uniform Courant number for all nodes. The time step is specified as inversely proportional to the volumetric flow rate which allows for a constant Courant number. In this manner, uniform and constant Courant numbers become possible as a main feature of RADYA and the value of a Courant number that is less or equal to unity is specified as input. Simplifying assumptions in the reduced order modeling include a first principles analytical approximation for the downcomer (cold leg) simulating the steam generator, and constant power (no neutron kinetics feedback) that is generated in a single node at the bottom of the hot leg. The transport of temperature is computed using an explicit scheme. The dynamic response is calculated using the density head difference between the riser (hot leg) and the downcomer (cold leg), where in each of these segments the nodal length weighted temperature is used to calculate the density head.

Figure 8 shows results from RADYA where the least stable response is that which is calculated for 1% of rated power and a Courant number of unity. It is noticed from this figure that the numerical noise persists as the algorithm is at the edge of numerical instability. A more numerically robust result is shown in Figure 9 with a Courant number of 0.8, which is considered more physically reasonable to account for diffusive processes not part of the model such as turbulence and heat conduction and heat exchange with pipe walls. Figure 10 and Figure 11 show more stable response at 20% of rated power for Courant numbers of unity and 0.8 respectively. Figure 12 and Figure 13 show very stable response at 100% of rated power at Courant numbers of unity and 0.8 respectively. The symptom of numerical sensitivity persists for a Courant number of unity regardless of the operating point. The decreasing decay ratio trend with increasing power is shown in Figure 14 for Courant numbers in the range of 0.6 to 1.0.

The results of RADYA confirm the important observation from PIM results where stability is improved for higher power, and despite the approximate nature of RADYA compared with PIM the calculated stability has been found to be in reasonable quantitative agreement. With respect to the effect of Courant number, RADYA results confirm that the decay ratio is slightly lower for smaller Courant numbers. However, the nodalization in RADYA (40 nodes in the riser and 40 nodes in the downcomer) is not as fine as in PIM (64 nodes in the hot leg and 75 nodes in the cold leg, see response to RAI 8801), which indicates that the damping effect in PIM calculations is expected to be less than in RADYA estimates.

Item 2:

To relate the above results to PIM, the nodalization in PIM is finer than in RADYA, and the Courant number in PIM calculations is 0.8 to 0.9 (see response to RAI 8801). Nodalization and time step studies which effectively change the Courant number (see response to RAI 8801) indicate decay ratio insensitivity as expected from the idealized RADYA results. From all the above exercises, it is estimated that the effect of numerical diffusion on PIM calculated decay ratio is within 0.1. It should be noted that there are physical modeling choices, namely considering the riser to be adiabatic, that introduce conservatisms greater than the numerical diffusion effect in PIM. Consequently, PIM conservatively predicts the decay ratio in the NuScale design considering biases and uncertainties relative to numerical diffusion of the solution algorithm.

Reference

1. J. Anderson et al., “TRACG Time Domain Analysis of Thermal Hydraulic Stability Sensitivity to Numerical Method and Comparison to Data,” Stability Symposium, Idaho Falls, August 10-11, 1989.

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Figure 1 Demonstration of diffused step function wave using explicit integration with different number of nodes and Courant numbers.

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Figure 2 Demonstration of sinusoidal wave attenuation at the far end and pipe average for 20 nodes and different Courant number values using explicit integration

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}}2(a),(c)

Figure 3 Demonstration of sinusoidal wave attenuation at the far end and pipe average for 50 nodes and different Courant number values using explicit integration

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}}2(a),(c)

Figure 4 Damping of a sinusoidal wave at the far end and pipe average for different number of nodes and Courant number values using explicit integration

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}}2(a),(c)

Figure 5 Demonstration of sinusoidal wave attenuation at the far end and pipe average for 20 nodes and different Courant number values using implicit integration

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}}2(a),(c)

Figure 6 Demonstration of sinusoidal wave attenuation at the far end and pipe average for 50 nodes and different Courant number values using implicit integration

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Figure 7 Damping of a sinusoidal wave at the far end and pipe average for different number of nodes and Courant number values using implicit integration

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Figure 8 Oscillatory flow response calculated with RADYA at 1% power and Courant number of 1.0

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Figure 9 Oscillatory flow response calculated with RADYA at 1% power and Courant number of 0.8

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Figure 10 Oscillatory flow response calculated with RADYA at 20% power and Courant number of 1.0

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Figure 11 Oscillatory flow response calculated with RADYA at 20% power and Courant number of 0.8

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Figure 12 Oscillatory flow response calculated with RADYA at 100% power and Courant number of 1.0

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Figure 13 Oscillatory flow response calculated with RADYA at 100% power and Courant number of 0.8

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Figure 14 Decay ratio trend with power calculated with RADYA at different Courant number values

Enclosure 3:

Affidavit of Zackary W. Rad, AF-0118-58327

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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 methods by which NuScale develops its stability analysis of the NuScale power module.

   NuScale has performed significant research and evaluation to develop a basis for this methods 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, 9105, eRAI No. 9105. 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 1/26/2018.

Zackary W. Rad