RAIO-0818-61457

August 17, 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. 9444 (eRAI No. 9444) 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. 9444 (eRAI No. 9444)," dated June 18, 2018
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. 9444:

- 15.09-8

Enclosure 1 is the proprietary version of the NuScale Response to NRC RAI No. 9444 (eRAI No. 9444). 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 Paul Infanger at 541-452-7351 or at pinfanger@nuscalepower.com.

Sincerely,

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

Distribution: Gregory Cranston, NRC, OWFN-8G9A
Samuel Lee, NRC, OWFN-8G9A
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Enclosure 1: NuScale Response to NRC Request for Additional Information eRAI No. 9444, proprietary

Enclosure 2: NuScale Response to NRC Request for Additional Information eRAI No. 9444, nonproprietary

Enclosure 3: Affidavit of Zackary W. Rad, AF-0818-61458

Enclosure 1:

NuScale Response to NRC Request for Additional Information eRAI No. 9444, proprietary

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Enclosure 2:

NuScale Response to NRC Request for Additional Information eRAI No. 9444, nonproprietary

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

eRAI No.: 9444
Date of RAI Issue: 06/18/2018

NRC Question No.: 15.09-8

Title 10 of the Code of the 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 (SAFDLs) are not exceeded during any condition of normal operation, including the effects of anticipated operational occurrences (AOOs). GDC 12, suppression of reactor power oscillations requires that the reactor core and associated coolant, control, and protections systems be designed to assure that power oscillations which can result in conditions exceeding specified acceptable fuel design limits are not possible or can be reliably and readily detected and suppressed. GDC 26 states that two independent reactivity control systems of different design principles shall be provided. One of the systems shall use control rods, preferably including a positive mean for inserting the rods, and shall be capable of reliably controlling reactivity changes to assure that under conditions of normal operation, including AOOs, and with appropriate margin for malfunctions such as stuck rods, SAFDLs are not exceeded.

The staff reviewed the response to the original RAI (RAI 8803) and found that the response was insufficient for the staff to reach a conclusion regarding whatever stability or thermal margins may be available during the limiting AOO. The response stated that, "analysis of a post-trip return to power during emergency core cooling system (ECCS) cooling conditions where a vapor volume exists atop the riser and cold leg is outside the scope of the stability Topical Report and the PIM code," however this does not address a return to power condition without or prior to ECCS actuation, nor does it confirm that under ECCS actuation the reactor would be subcritical. Further, the scope of the stability Topical Report and Section 15.9 in the FSAR indicate that the stability Topical Report provides the methodology and analyses supporting GDC 12.

In the Stability TR, an analysis is provided of a limiting depressurization AOO, but this analysis does not consider the possibility of recriticality and return to power as pressure decreases. Either with or without ECCS actuation, the stability solution (as described by the Topical Report) must be effective in preventing oscillations that exceed SAFDLs in order to be in compliance with GDC 12.

Therefore in order to make an affirmative finding with regard to the above regulatory requirements important to safety, the NRC staff requests the following supplemental information be updated in the Stability TR and/or FSAR sections 15.0.6 or 15.9, as appropriate:

I. Neither the response to RAI 8803, nor the return to power analysis in FSAR 15.0.6, address the possibility of flow/power instabilities, which may occur under the DHRS cooldown scenario. FSAR Section 15.0.6 goes on to state that subcriticality is achieved when the ECCS is actuated (for decay heat above 100 kW). For the staff to reach a reasonable assurance finding regarding GDCs 10 and 12 the staff is requesting the following:

   1. To address RCS stability during a DHRS cooldown the staff is requesting an evaluation of stability prior to ECCS actuation at 24 hours using an appropriate code(s) or method(s) capable of determining the following parameters:

      - a description of the incidence and prevalence of subcooling boiling including any local effects due to the stuck rod
      - minimum riser subcooling margin (or maximum riser void fraction)
      - the decay ratio (DR), or if DR > 1.0, a calculation showing the limit cycle flow oscillation
      - oscillation frequency

   2. If a decay ratio greater than 1.0 exists, demonstrate that the proposed stability solution is effective in precluding instabilities that could challenge the SAFDLs.

   3. To address the reactor system behavior during a DHRS cooldown, and that subcriticality occurs upon ECCS actuation such that instabilities are not a CHF concern; demonstrate the reactivity parameters (e.g., density reactivity coefficient) used in the FSAR section 15.0.6 return to power analyses are conservatively determined using a qualified code such as SIMULATE and cover the range of expected RCS conditions.

   4. If flow oscillations occur during the DHRS cooldown scenario, evaluate MCHFR at time of minimum flow using a qualified systems code such as NRELAP5. Compute final MCHFR values using a subchannel code, for example VIPRE-01, or justify why a subchannel analysis is not necessary.

II. Neither the response to RAI 8803, nor the return to power analysis in FSAR 15.0.6, address the possibility of flow/power instabilities, which may occur during a slow depressurization transient following reactor trip. The Stability TR provides an analysis of a limiting depressurization scenario to demonstrate the function of the module protection system to trip the reactor, however, the analysis does not consider the possibility of a

return to power if one control rod remains stuck out of the reactor core. If the depressurization AOO would result in ECCS actuation, the staff requests an analysis that addresses both the pre- and post-ECCS actuation phases of the transient. For the staff to reach a reasonable assurance finding regarding GDCs 10 and 12 the staff is requesting the following:

1. To address the initial conditions of the reactor system prior to the initiation of the limiting AOO and to address the potential for a return to power as the RCS depressurizes, the staff requests an analysis for the most conservative combination of nuclear design parameters such as reactivity feedback parameters, critical boron concentration, burnup state, initial primary side temperature, power distribution, etc. that shows the margin to recriticality with the worst rod stuck out as a function of system pressure.

2. For points identified in (1) that return to power, or may return to power given consideration of uncertainties, perform an analysis using appropriate, qualified methods that provides:

   - the hot assembly peaking factor
   - core temperature rise
   - a description of the incidence and prevalence of subcooling boiling
   - core flow rate
   - hot assembly flow rate
   - minimum riser subcooling margin (or maximum riser void fraction)
   - the DR, or if DR > 1.0, a calculation showing the limit cycle flow oscillation
   - oscillation frequency

3. If flow oscillations occur, calculate the MCHFR using a qualified method. It is acceptable to provide this result assuming steady-state conditions with a flow equal to the minimum flow observed during the oscillation.

4. If MCHFR violates applicable AOO related limits, describe how the stability solution is effective in precluding instabilities that could challenge the SAFDLs.

NuScale Response:

The concerns expressed in this RAI items (I) and (II) overlap and can be addressed by analyzing cooldown events accompanied with return to criticality, with or without actuation of the emergency core cooling system (ECCS). The analysis applies a combination of NRELAP5 and PIM runs in order to fully address the phenomena based on applicability of the two codes.

In the event of an extended decay heat removal system (DHRS) cooldown, when the reactor coolant system (RCS) is at low boron concentrations and the chemical and volume control system (CVCS) is unavailable to add boron, it may be possible for the decay heat removal system to sufficiently cool the core such that it would reestablish criticality and fission power generation. In order to bound all possible core power levels, the event is analyzed to generate a maximum power overshoot that is much larger, as shown in Figure 1 of this RAI response, than the eventual steady state power level.

For this analysis, it is assumed that an end of cycle (EOC) reactor trip occurs with the worst rod stuck out (WRSO), the subsequent DHRS cooldown is left unmitigated and boron addition does not occur.

In the event that the highly reliable DC power is unavailable concurrent with the initiating event, the ECCS would be actuated (trip valves open), but if the RCS pressure is above the inadvertent actuation block (IAB) pressure, the ECCS valves would not open. During an extended DHRS cooling event, RCS pressure decreases due to RPV heat loss and RCS shrinkage causing an expansion of the pressurizer (PZR) vapor space. Although unlikely, if the initial PZR pressure and level were sufficient, it is possible to postulate an IAB release concurrent with the power peak. This scenario will generate the most challenging CHF conditions and, therefore, in order to bound all other possible over cooling return to power event sequences, an analysis of this scenario is presented in response to this RAI.

<u>Simulated sequence of events leading to return to power without ECCS actuation</u>

The event is analyzed using NRELAP5. The average RCS temperature is initialized at 220 ºC (428 ºF). The core initial power is 1.6 MW (MW thermal throughout response). The reactor trips and it is assumed that the highest worth control rod is stuck out. The RCS then slowly cools down until the core reaches criticality again. As a result, the power level spikes before it comes back down in response to negative reactivity feedback, and oscillates before eventually reaching critical steady state conditions. The power and flow oscillations predicted by NRELAP5 shown in Figure 1 and Figure 2 of this RAI response. The system is stable with a {{ }}$^{2(a),(c)}$. Since NRELAP5 is not used as the primary tool for stability assessment, the NRELAP5 calculated steady conditions after the return to power were used to provide the initial conditions for PIM.

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}}2(a),(c)

Figure 1. Power as a function of time due to return to criticality without ECCS actuation.

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}}2(a),(c)

Figure 2. Flow rate as a function of time due to return to criticality without ECCS.

The reactor power for PIM calculations is {{ }}2(a),(c), of which decay heat contributes {{ }}2(a),(c). The initial flow rate is {{ }}2(a),(c), system pressure of {{ }}2(a),(c), and the core inlet temperature is {{ }}2(a),(c). Variations of PIM calculations include a conservative reduction of the moderator reactivity coefficient up to a zero moderator reactivity coefficient. The calculated decay ratio for the nominal moderator reactivity coefficient is {{ }}2(a),(c) for the conservative zero moderator reactivity. The {{ }}2(a),(c) corresponds to a higher frequency oscillation mode than the one resolved by NRELAP5. A substantial subcooling of over 100 ºC (180ºF) was maintained for the entire transient and no voids were generated. The RCS pressure decreases asymptotically once the power response equalizes due to the mitigation of the RCS cooldown and resultant shrinkage. Heat loss from the RPV vapor space is the cause of continued pressure decay, however the timing to reach saturated conditions is conservatively estimated to be more than {{ }}2(a),(c), which is beyond the time required to reach the ECCS actuation at 24 hours, following an extended loss of AC power. This latter scenario immediately results in two phase conditions which are evaluated further in this response.

It should be noted that the moderator reactivity coefficient plays a role in both the return to criticality and stability. For a high moderator reactivity coefficient, as is the case of very low boron characteristic of EOC conditions, the cooling introduces the maximum positive reactivity making the return to power possible; on the other hand, the large moderator coefficient stabilizes coupled flow and power oscillations. In order to make the conservative conclusion that the return to power conditions are stable, the high moderator coefficient is retained in the transient leading to the return to power, while the stability calculation is allowed to use a reduced moderator reactivity coefficient for parametric study.

<u>Simulated sequence of events with ECCS actuation</u>

The ECCS actuation case is analyzed using NRELAP5 only. {{

}}2(a),(c)

It is observed from the NRELAP5 analysis that the system does not reach a fixed point steady state. Rather, the state variables of power and flow undergo irregular fluctuations around a would-be steady point which acts as the attractor. As shown in Figure 4, these fluctuations are bounded and no physical mechanism was identified that may lead to their amplitude growth. The introduction of positive reactivity and the increased power response result in vapor generation in the near stagnant flow, to the effect that fluid is expelled at both ends of the core and results in

inlet flow reversal. When the void fraction increases in the core, the negative reactivity causes the power to drop and the voids collapse - and the cycle is repeated. The irregular fluctuations are shown in the Figure 5, which is a zoomed in view of Figure 4. The corresponding power spectral density associated with the time shown in Figure 5 is shown in Figure 6 and demonstrates the presence of multiple frequencies contributing to the complexity of the interaction of different processes. The range of fluctuations is constrained by the void fraction, which otherwise would introduce too much negative reactivity to maintain power. The bounded nature of the fluctuations combined with low average power assures the minimum critical heat flux ratio (MCHFR) remaining well above unity (as shown in Figure 7).

It is noted the extended ECCS event presented in this RAI response includes conservative core operating assumptions well beyond the physically possible operating conditions. Specific to this event response is the assumption that the event could initiate from a zero boron and startup decay heat core configuration. As noted in FSAR Section 15.0.6 and further described in NuScale's response to RAI 9505 (ML18190A449), a conservative analysis of the end of cycle core condition demonstrates the level of decay heat necessary to generate enough voiding to keep the core subcritical is well below the 72 hour EOC decay heat. This bounding analysis of the ECCS oscillatory condition is presented from the perspective of demonstrating the conservatism of the event already presented as the limiting condition in FSAR Section 15.0.6.

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}}2(a),(c)

Figure 3. Power as a function of time following return to criticality with ECCS actuation.

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}}2(a),(c)

Figure 4. Core inlet flow rate as a function of time following return to criticality with ECCS actuation.

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}}2(a),(c)

Figure 5. Zoomed in view of Figure 4 showing irregular fluctuation of core inlet flow rate as a function of time following return to criticality with ECCS actuation.

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}}2(a),(c)

Figure 6. Power spectral density of the flow rate in Figure 5.

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}}2(a),(c)

Figure 7. Minimum critical heat flux ratio for the hot channel as function of time.

Response to individual items in the RAI

I-1The analysis was performed using NRELAP5 and PIM as described above.

- The coolant temperature is too low relative to saturation temperature to allow subcooled boiling following the initial pulse. At the core exit an excess of 100 ºC subcooling is observed for the entire transient. The low power, and excessive subcooling preclude any subcooled boiling in the hot assembly or bulk core. Note that subcooled boiling is a stabilizing phenomenon.
- The riser remained subcooled with no void.
- The DR (Decay Ratio)<<1 has been observed. The nominal moderator reactivity coeficient case calculates {{ }}2(a),(c).
- Oscillation frequency was calculated to be approximately {{ }}2(a),(c).

I-2 No decay ratio greater than unity was observed.

I-3 The MDC used in the analysis presented in FSAR section 15.0.6 is calculated by SIMULATE5 for conditions with very low Boron in the moderator. This is conservative as the peak return to power event is postulated to occur based on the lack of boron in the moderator. Analyzing the system with boron in the moderator reduces the peak return to power, and MCHFR is most challenged at the time of peak power. Thus, other MDCs corresponding with boron in the moderator result in smaller peak powers and are non-conservative. However, the PIM calculations include zero MDC to conservatively verify that the system remains stable with a decay ratio of {{ }}2(a),(c).

I-4 As demonstrated in the above PIM analysis, sustained oscillations are not predicted, therefore a subchannel analysis is not necessary.

II-1 The most conservative combination of nuclear design parameters is associated with zero boron at EOC, where the extended RCS cooldown event is analyzed showing the pre- and post-ECCS actuation return to power conditions. The recriticality condition is driven by moderator feedback from RCS temperature and is not dependent on pressure. For the post-ECCS cooldown mode the system is operating in a saturated condition as described previously in this response. Details of the system thermal hydraulic response to this event are presented below in the response to item II-2 of this RAI.

II-2 The analysis tool (NRELAP5) is capable of accounting for the bullet items. The NRELAP5 model includes two channels in core (an average and a hot channel).

- A hot assembly peaking factor of 6.5 is applied consistent with FSAR Section 15.0.6.
- Core temperature rise for the ECCS cooling case is included in Figure 8.

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}}2(a),(c)

Figure 8. Core temperature rise as a function of time for the ECCS cooling case.

- ECCS cooling operates in a saturated boiling phase in the core region with condensed liquid recirculated from containment, therefore subcooled boiling is not a phenomenon of significance to the overall transient response.
- Core flow rate is included in Figure 4 of this RAI response. Hot assembly flow rate is included in Figure 9 of this RAI response.

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}}2(a),(c)

Figure 9. Hot channel inlet flow rate as function of time for return to criticality with ECCS actuation.

- Maximum Riser Void: the water level has dropped into the riser and therefore the upper part of the riser is voided, as shown in Figure 10 of this RAI response. The riser inlet void is given in Figure 11 of this RAI response.

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}}2(a),(c)

Figure 10. Riser collapsed water level as function of time following return to criticality with ECCS actuation.

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}}2(a),(c)

Figure 11. Core outlet void fraction as function of time following return to criticality with ECCS actuation.

- Decay Ratio as a linear parameter is not defined in this case as the system settles into irregular oscillations that do not grow or decay to a steady state

- Oscillation Frequency: multiple frequencies are simultaneously excited as shown in Figure 6 of this RAI response.

II-3 MCHFR results from NRELAP5 are provided in Figure 7 of this RAI response, and no violation of limits occurred.

II-4 MCHFR AOO limits were not violated in these analyses.

Impact on DCA:

There are no impacts to the DCA as a result of this response.

Enclosure 3:

Affidavit of Zackary W. Rad, AF-0818-61458

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 stability analysis of the NuScale power module.

    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. 9444, eRAI 9444. 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 August 17, 2018.

Zackary W. Rad