NUSCALE POWER™

RAIO-1017-56516

October 10, 2017

Docket No. 52-048

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

SUBJECT: NuScale Power, LLC Response to NRC Request for Additional Information No. 161 (eRAI No. 9043) on the NuScale Design Certification Application

REFERENCE: U.S. Nuclear Regulatory Commission, "Request for Additional Information No. 161 (eRAI No. 9043)," dated August 11, 2017

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. 9043:

- 19-26

Enclosure 1 is the proprietary version of the NuScale Response to NRC RAI No. 161 (eRAI No. 9043). 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
Samuel Lee, NRC, OWFN-8G9A
Rani Franovich, NRC, OWFN-8G9A

Enclosure 1: NuScale Response to NRC Request for Additional Information eRAI No. 9043, proprietary

Enclosure 2: NuScale Response to NRC Request for Additional Information eRAI No. 9043, nonproprietary

Enclosure 3: Affidavit of Zackary W. Rad, AF-1017-56517

Enclosure 1:

NuScale Response to NRC Request for Additional Information eRAI No. 9043, proprietary

Enclosure 2:

NuScale Response to NRC Request for Additional Information eRAI No. 9043, nonproprietary

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

eRAI No.: 9043
Date of RAI Issue: 08/11/2017

NRC Question No.: 19-26

Regulatory Basis

10 CFR 52.47(a)(27) states that a Design Certification (DC) application must contain a Final Safety Analysis Report (FSAR) that includes a description of the design-specific probabilistic risk assessment (PRA) and its results. 10 CFR 52.47(a)(23) states that a DC application for light-water reactor (LWR) designs must contain an FSAR that includes a description and analysis of design features for the prevention and mitigation of severe accidents (e.g., challenges to containment integrity caused by core- concrete interaction, steam explosion, high-pressure melt ejection, hydrogen combustion, and containment bypass). Standard Review Plan 19.0 acceptance criteria for the applicant's severe accident analyses include a large release frequency of less than 10-6 per year and a conditional containment failure probability of less than 0.1. The staff must make a finding that the applicant has performed an adequate evaluation of the risk from severe accidents.

Request for additional information

The applicant's PRA and description and analysis of design features for prevention and mitigation of severe accidents included an analysis of in-vessel retention of corium in the reactor vessel lower plenum and the containment lower plenum. The staff reviewed the applicant's analysis of in-vessel retention documented in FSAR Chapter 19 and in the supporting documents "Analysis of In-Vessel Retention in the Reactor Pressure Vessel," ER-P020-3635-R0, and "Analysis of In-Vessel Retention in the Containment Vessel," ER-P020-4450-R0. The applicant is requested to include the following additional information in FSAR Chapter 19. For the staff to make a finding that the applicant has performed an adequate evaluation of the risk from severe accidents in accordance with SRP 19.0, the applicant is requested to respond to the questions below.

In-vessel Retention in the reactor pressure vessel (RPV)

a) The applicant used the critical heat fluxes measured in the Subscale Boundary Layer Boiling (SBLB) experiments to show that its predicted heat fluxes on the curved surfaces of the NuScale reactor vessel bottom head would not lead to failure. The geometry of the NuScale bottom head and surrounding containment is different from that of the SBSB experiments. For example, the bottom head has an integral seismic retention pin, and the SBLB experiments did not. The local critical heat flux depends on flow patterns (e.g., instabilities and recirculation can occur at junctions such as the where the seismic retention pin is joined to the hemispherical surface of the bottom head). In addition, the staff notes that different AP1000 reactor vessel bottom head and insulation configurations resulted in different experimentally measured critical heat fluxes in the AP1000 experimental program. The applicant is requested to provide justification for the use of the SBLB experimentally determined critical heat fluxes for the NuScale RPV bottom head.

b) The applicant performed ANSYS calculations assuming core debris relocated into the RPV lower plenum to estimate a heat flux of 330 kW/m2 at the junction of the hemispherical bottom head and the seismic retention pin. The applicant compared this to a critical heat flux of 400 kW/m2 from the SBLB experiments to demonstrate the robustness of its design to severe accident challenges and to assign an RPV lower head failure probability of zero in the Level 2 Containment Event Tree. This 20% difference between the estimated heat flux and the critical heat flux does not appear to be sufficiently large to conclude that RPV lower head failure probability is zero and in-vessel retention is certain even assuming that the SBLB experiments are representative of NuScale. Specifically, the applicant is requested to address the uncertainties in the analysis including the uncertainty in the assumed critical heat flux and uncertainties in the applicant's ANSYS prediction of the heat flux. Uncertainties could include the time of relocation into the lower plenum, amount of material relocating, and the amount of heat generation within the postulated metallic layer over the corium. The relocation time and amount of material relocating can affect the analysis of in-vessel retention through the decay power and the height of the debris bed and can vary based on scenario and phenomenological assumptions.

In-vessel retention in the containment vessel (CNV)

c) The applicant concluded that in-vessel retention in the CNV is certain because in-vessel retention in the RPV is certain and the CNV configuration is more favorable to cooling due to the presence of water in the CNV and because the same debris mass in the CNV has a greater surface area and a thinner body with a resulting lower heat flux. The applicant is requested to address the uncertainty in the critical heat flux for the CNV bottom head, considering that (1) the SBLB test geometry was hemispherical and the CNV bottom head is not; and (2) the CVN bottom head has a skirt and is 5 inches above the pool floor.

d) The applicant's analysis did not include a case in which local heat fluxes could be increased by the focusing effect of a metallic layer overlying core debris. The applicant believes a molten metal layer on top of an oxidic melt is unrealistic in the containment lower plenum because of the presence of water there. However, conditions leading to a focusing effect could occur if failure of the reactor vessel lower head involves relocation of metals into the CNV lower plenum. The applicant is requested to justify its belief that water prevents conditions leading to a focusing effect in the CNV lower plenum.

e) The applicant states that to allow flow between the skirted region and the region outside the skirt, there are {{ }}$^{2(a),(c)}$ large {{ }}$^{2(a),(c)}$ slots spaced evenly about the vessel just below the point where the skirt and the dome meet and {{ }}$^{2(a),(c)}$ smaller {{ }}$^{2(a),(c)}$ slots evenly spaced about the vessel just above the bottom of the skirt. The applicant performed an analysis to show that the steam generated under the skirt by core debris in the containment lower plenum can effectively escape through the top holes preventing conditions from reaching local dry-out and failure of the containment dome. The applicant is requested to consider and evaluate the potential of the complex geometry of the skirted region (which is heated from above) to cause complex flow patterns (e.g., a countercurrent flow of steam and water developing in the top slots) that could prevent sufficient steam from escaping.

NuScale Response:

In-vessel Retention in the reactor pressure vessel (RPV)

Item a): The experimentally determined critical heat flux (CHF) estimates from the subscale boundary layer boiling (SBLB) tests were applied to the surfaces of the reactor pressure vessel (RPV) lower head of the NuScale Power Module (NPM) that matched or exceeded the associated inclination angles of the experiments. The local inclination angle is associated with the effective buoyancy force that moves generated steam from its nucleation site. With the exception of fluid properties, the inclination angle is the controlling factor in determining whether the CHF would be greater than that observed during the tests. Thus, the SBLB experimentally determined CHF values are applicable if the local inclination angle in the area of the NPM matches the SBLB test angle. The use of the SBLB experimentally determined CHF values is conservative if the local NPM inclination angle exceeds the SBLB test angle. While there are differences between the geometry of the RPV lower head and the SBLB experiments, such as the transition from the vertical alignment pin to the hemispherical portion of the lower head, those differences do not significantly hinder the upward movement of steam and, as such, do not significantly influence the CHF.

Further, the application of the empirical CHF estimates, derived for saturated atmospheric conditions, is conservative due to the expected pressurization and subcooling of the water in the containment vessel (CNV) during a postulated severe accident with core retention in the RPV. The CHF associated with a subcooled condition is greater than the CHF for saturated conditions due to the sensible heat required to bring the liquid to the boiling point as well as the interfacial condensation of steam by subcooled liquid, which reduces overall steam voiding. The CHF associated with increased pressure is greater than atmospheric pressure conditions primarily due to increased steam density, resulting in smaller bubbles and a more easily wetted surface. Consideration of subcooling and increased pressure would result in a higher CHF than the saturated atmospheric case. Consequently, CHF estimates for saturated atmospheric conditions are conservative relative to expected conditions within the NPM.

In summary, the geometry of the NPM lower head is sufficiently similar to the SBLB

---

experimental configuration that CHF estimates can be appropriately applied where the local inclination angles match or exceed those of the experiments. Further, the use of CHF estimates defined at saturated atmospheric conditions is conservative with regard to the pressurized, subooled CNV environment associated with a postulated severe accident.

FSAR Section 19.2.3.2.1 ("Basis for Evaluating Core Debris Retention in RPV") has been modified to include this perspective on the CHF values that were used in the analysis.

Item b): The approach for demonstrating in-vessel retention (IVR) in the RPV does not rely on a best estimate analysis, which would then need to be accompanied by an evaluation of uncertainty. Instead, the analysis uses methods with conservative or bounding inputs to demonstrate success of IVR in the RPV, given an intact containment. Given this approach, the results are already bounding and, thus, consideration of uncertainty was judged not to be appropriate.

FSAR Section 19.2.3.2.1 ("Summary of Retention of Core Debris in the Reactor Pressure Vessel") has been modified to summarize the conservatism used in the IVR analysis.

In-vessel retention in the containment vessel (CNV):

As discussed in the response to Item b) of Question 19-26, the RPV-IVR analysis concludes that IVR in the RPV is assured when the containment has not already failed. As such, demonstrating the capability of IVR in the CNV is not necessary for addressing severe accident phenomena that challenge containment integrity. Thus, the IVR capability of the CNV is considered from the perspective of evaluating the defense-in-depth capability and robustness of the NuScale design with respect to severe accident mitigation.

FSAR Section 19.2.3.2.2 has been modified to clarify the purpose of the CNV-IVR analysis.

Item c): The CNV IVR analysis does not include a detailed evaluation of heat fluxes on the lower head for comparison with CHF limits. As stated in FSAR Section 19.2.3.2.2 ("Basis for Evaluating Core Debris Retention in the Containment Vessel"), the heat fluxes on the CNV lower head would necessarily be less than those for the RPV lower head because of the larger CNV head, heat removal from the top surface of postulated relocated core debris, and lower decay heat. As discussed in the response to Item a) the CHF limits derived from the SBLB tests are conservative with regard to the NuScale configuration. As noted in Item c) of Question 19-26, the evident differences are that the CNV lower head is torispherical and the SBLB head is hemispherical, and that the space underneath the CNV is bounded by the support skirt and the reactor pool floor whereas the SBLB tests were performed in an open pool. With regard to these points, the following information is provided:

A torisphere is formed as the intersection of a spherical cap and a tangent torus. The crown region of a torisphere is identical to a hemisphere with the same radius of curvature. In the context of CHF, for which the angle of inclination is the primary controlling factor, empirical formulations for hemispheres are appropriate for torispheres in the crown region where CHF estimates are lowest. Because heat fluxes at all locations on the CNV lower head will remain below the minimum SBLB CHF estimate, no uncertainty regarding the shape of the lower head surface is introduced.

NuScale has also considered that the confined space beneath the CNV lower head may influence heat removal by affecting the convective flows underneath the lower head. To address this issue, the width of the two phase boundary layer for the open pool boiling case was compared to the dimensions of the gap between the CNV lower head and the reactor pool floor. Employing an analytical model, the estimated two-phase boundary layer thickness at the bottom center of the lower head was conservatively calculated to be less than the minimum gap between the CNV lower head and the pool floor. This result suggests that the open pool boiling case is a reasonable approximation for the geometry underneath the CNV lower head.

FSAR Section 19.2.3.2.2 ("Basis for Evaluating Core Debris Retention in the Containment Vessel") has been modified to clarify the basis for concluding that the CHF estimates from the SBLB tests are appropriate for the geometry of the CNV lower head.

Item d): NuScale considers that the potential for a focusing effect of core debris in the CNV is physically unrealistic in terms of challenging the integrity of the CNV, and, thus it is not explicitly evaluated in the CNV IVR analysis. The primary basis for this judgment is that the overlying water pool in the containment would provide effective cooling of the top surface of the debris, preventing the formation of a molten metallic layer and keeping the top of the core debris cool.

Even in a postulated scenario in which a stable insulating vapor blanket forms above the debris and allows for a conductive molten metallic layer, the heat transfer by radiation alone to the water pool overlying the debris would mitigate a potential focusing effect. As a result of this heat removal, very little, if any, heat flowing into the metallic layer from the oxidic debris would remain available to focus on the CNV wall. Additionally, for such a stratified molten debris configuration to occur in the CNV, the RPV lower head would almost certainly be molten as well and contribute to the metal layer. This would add substantial thickness to the layer, further weakening the focusing effect.

FSAR Section 19.2.3.2.2 ("Evaluation of Core Debris Configuration in the Containment Vessel") has been modified to clarify why the focusing effect on the CNV wall is judged to be physically unrealistic.

Item e): In addition to generating steam, the heat flow from the CNV would warm the subcooled liquid in the skirted region. The density of both the liquid and steam in the skirted region would be substantially less than the density of the fluid outside of the skirt. The density difference would create conditions for stable natural circulation flow to develop with liquid inflow from the lower slots and two-phase outflow through the top slots. Liquid inflow through the top slots is not possible in this configuration because the buoyancy head due to increased temperature in the skirted region is large relative to the pressure drop associated with inflow through the lower holes. As a result, the net pressure drop through the top slots is positive in the outward direction. Consequently, the escape of steam through the top slots would be unimpeded by complex flow effects such as recirculation or counter current flow.

FSAR Section 19.2.3.2.2 (“Summary of Analysis Results”) has been modified to include discussion of the natural circulation flow that would develop with inflow through the bottom slots and two-phase outflow through the top slots.

Impact on DCA:

FSAR Section 19.2.3.2 has been revised as described in the response above and as shown in the markup provided with this response.

challenge the section of the RPV wall it is in contact with. This is because the convective forces and high thermal conductivity of the molten metallic layer can focus the heat flow from the top of the oxidic debris onto a relatively small area along the RPV wall; the focusing effect increases as the area in contact with the RPV decreases.

RAI 19-26

Basis for Evaluating Core Debris Retention in RPV

The outside surface of the RPV lower head is cooled by the water in the CNV. Heat transfer from the external surface of the RPV lower head is most effective if conditions remain in the nucleate boiling regime~~; in~~. In this regime, there is a high heat flux at relatively low excess temperature of the RPV wall above the temperature of the water in the CNV. In the nucleate boiling regime, the heat flux and excess temperature of the RPV wall increase at a roughly proportional rate until the maximum CHF is approached. At this heat flux, generated steam has difficulty departing from the surface at a sufficient rate for the surface to remain wetted. ~~When the~~If the external heat flux is increased marginally beyond this point, the heat transfer regime transitions to film boiling and the excess temperature of the RPV wall increases dramatically. ~~This temperature difference is relevant to the evaluation of the RPV to retain its integrity because a higher temperature difference could cause loss of RPV integrity; thus, it is desired to remain in the nucleate boiling regime.~~If instead the excess surface temperature is increased marginally beyond this point, the heat transfer regime enters transition boiling and the local external heat flux decreases. The latter condition applies for geometries with significant thermal heat capacity and the ability to effectively conduct heat away from localized regions of degraded heat transfer. Remaining in the nucleate boiling regime, however, ensures that the excess temperature of the RPV wall remains small and the integrity of the RPV is assured.

Experimental studies related to IVR were reviewed for applicability to the NuScale design. The studies relevant to NuScale capability to retain a damaged core in the RPV are those for the downward-facing, heated surface with curvature, as provided by NUREG/CR-6507 (Reference 19.2-9), Guo and El-Genk (Reference 19.2-10) and Theofanous (Reference 19.2-11, Reference 19.2-12). The studies demonstrate the CHF value is primarily controlled by the effectiveness of generated steam in escaping from underneath the RPV surface (a flat plate is not as efficient in venting steam as a curved surface) and the amount of subcooling in the surrounding water pool. The studies provide insights for the underside of the RPV head as well as the vertical portion of the RPV wall. The studies provide a range of CHF values for the bottom center of a hemispherical surface like the RPV lower head and larger CHF values for vertical surfaces like the vertical portion of the RPV wall. The CHF results were strongly sensitive to the ability of a surface to vent steam from the region in which it is generated.

RAI 19-26

The Subscale Boundary Layer Boiling (SBLB) experiment described in NUREG/CR-6507 is the most relevant to an in-vessel retention-RPV analysis in which the RPV lower head is a clean hemisphere (or a shape close to a hemisphere) and the water pool is saturated or subcooled. ~~Although the lower head design of the NuScale Power Module (NPM) diverges from a clean hemisphere due to the seismic retention pin, the results of the Subscale Boundary Layer Boiling tests remain applicable for the curved portion of the lower head because the NPM design does not include features that hinder the upward movement of steam.~~ The study indicates that, at saturated atmospheric conditions, a ~~minimum~~ CHF of 400 kW/m^2 is appropriate for the ~~lower RPV head~~bottom of a hemispherical surface and 1 MW/m^2 for vertical surfaces. Although the lower head design of the NPM diverges from a clean hemisphere due to the seismic retention pin, the results of the SBLB tests remain applicable for the curved portion of the lower head because the NPM design does not include features that hinder the upward movement of steam. The vertical portion of the retention pin as well as the transition fillet region are necessarily more vertically oriented than ~~horizontal~~the bottom of the hemispherical surface and can thus be conservatively assessed against the ~~same CHF limit~~400 kW/m^2 CHF estimate. The results of the Guo and El Genk experiments (Reference 19.2-10) are judged applicable to the flat bottom surface of the retention pin; that study determines a minimum CHF of 200 kW/m^2 for saturated atmospheric conditions.

RAI 19-26

Although the in-vessel retention-RPV analysis employs CHF estimates that were derived for saturated fluid at atmospheric pressure, the coolant in the CNV during an in-vessel relocation event will be significantly subcooled and pressurized due to the presence of noncondensible hydrogen in the containment. Subcooling enhances CHF due to the sensible heat required to initiate the boiling process and due to interfacial condensation of generated steam which reduces overall steam voiding. Increased pressure enhances CHF due to increased vapor density, resulting in smaller bubbles and a more easily wetted surface. Considering the degree of subcooling and pressurization observed following core relocation for the NPM, the CHF would increase in comparison to the saturated atmospheric condition as quantified by the analytical model presented in NUREG/CR-6507. As such, CHF estimates for saturated atmospheric conditions are conservative relative to expected conditions within the NPM.

RAI 19-26

To evaluate the structural capability of the RPV to retain a core debris bed, ~~it is assumed that the surrounding CNV water pool is at saturated conditions~~the concept of heat flux limit wall thickness is introduced. From Theofanous (Reference 19.2-7), steel maintains its full strength when its temperature does not exceed 900 degrees K (627 degrees C). If the RPV lower head is in steady-state contact with core debris on the interior wall and cold water on the exterior, a linear temperature profile is established across the RPV lower head wall thickness. The temperature at a certain depth in the wall equals 900 degrees K, given that the interior surface temperature exceeds 900 degrees K due to contact with core debris. Conversely, the distance from the cold wall surface to the 900-degree K point defines the thickness of the RPV that can be relied upon to support the lower head and its contents. This distance is termed the “heat flux limited wall thickness”. The RPV can retain adequate wall thickness only if the outside wall surface remains below 900

The results of the simulation are illustrated in Figure 19.2-3 (Temperature Profile of RPV Lower Head). The figure illustrates that the portion of the RPV lower head shell thickness kept below 900 degrees K (627 degrees C) is much greater than 1.1 cm. This implies that the RPV lower head does not fail structurally under the thermal attack from the relocated core debris.

The RPV bottom head, the transition region to the alignment feature, and all surfaces of the alignment feature were also evaluated in terms of CHF. The intent of the evaluation was to ensure the maximum heat flux at any point on the outer surface of the RPV lower head is less than the local CHF. Figure 19.2-4 and Figure 19.2-5 illustrate the heat flux on the RPV lower head, vertical portion of the alignment pin and transition fillet. The figure illustrates that the maximum heat flux at the RPV to alignment pin transition is 333 kW/m^2. As stated earlier, experimental studies for hemispherical surfaces suggest that the CHF for this geometry is at least 400 kW/m^2. Figure 19.2-6 illustrates the heat flux on the retention pin bottom surface. This figure indicates that the maximum heat flux on the bottom of the alignment pin is 43 kW/m^2. Experimental studies demonstrate the CHF for this geometry is at least 200 kW/m^2. The results demonstrate that thermal attack from oxidic debris does not result in a challenge to lower head or alignment pin integrity.

An evaluation of the focusing effect associated with a potential metallic layer floating above the oxidic materials was performed. This evaluation assumes the oxidic core debris is not porous because porosity would prevent the formation of a distinct metallic layer. The height of the metallic layer was calculated based on limiting oxide and metallic mass ratios in the RPV lower plenum calculated by MELCOR. The heat flux is inversely proportional to thickness; theoretically the flux could be maximized with an infinitely thin layer. However, practically, the heat flux from a very thin layer becomes limited because of constraints on the convective and conductive heat transfer radially across the layer. Additionally, when the thickness of the metallic layer is significantly less than the thickness of the vessel wall, conduction in the shell is expected to dissipate the heat axially such that the peak heat flux on the outside surface of the RPV is drastically reduced. The CHF hand-calculated at the location on the RPV vessel of the potential metallic layer is 928 kW/m^2. Conservative calculations, neglecting radiation from the top of the layer, determined the peak heat flux from the side of the layer is 618.3 kW/m^2, or a margin of about 50 percent. The peak heat flux for a best-estimate calculation with radiation included is only 175.5 kW/m^2. Thus, the focusing effect from a potential metallic layer above oxidic debris does not result in a challenge to RPV integrity.

RAI 19-26

Summary of Retention of Core Debris in the Reactor Pressure Vessel

An evaluation of the capability of the RPV to retain core debris after a severe accident has been performed using conservative ANSYS modeling and hand calculations. The evaluation considers potential core configurations in the lower RPV head after a severe accident and heat removal characteristics of the RPV, which is immersed in the water retained by the CNV. Boundary conditions for a severe accident are obtained from MELCOR simulations. ~~The analysis concluded that CHF is not exceeded in any location for either bounding debris configuration nor is the minimum structural thickness exceeded.~~With bounding inputs and conservative methods, the analysis concludes that the thermal and structural integrity of the lower head is maintained in the event of in-vessel core relocation and IVR in the RPV is assured.

RAI 19-26

The conservatisms employed in the IVR analysis include:

RAI 19-26

- bounding decay heat load. Entire core relocates at the earliest onset of relocation.

RAI 19-26

- no credit for heat removal from the top surface of debris.

RAI 19-26

- maximized heat transfer to metallic layer for evaluation of the focusing effect.

RAI 19-26

- zero heat transfer to metallic layer for evaluation of thermal attack from oxidic debris.

RAI 19-26

- solid debris configuration assumed for maximum heat flux to bottom of lower head (region most susceptible to reach CHF).

RAI 19-26

- no credit for CHF enhancement from subcooling or pressurization of the containment pool.

RAI 19-26

- margin of maximum heat flux to CHF bounds the actual margin to lower head failure.

RAI 19-26

The design characteristics of the NPM that ~~result~~improve ~~in~~ the in-vessel retention-RPV capability compared to traditional large light water reactors are:

- retention of water in the CNV allowing passive heat transfer. Loss of RCS inventory and core uncovery is associated with core damage events. Only the potential accident sequences in which containment is isolated are relevant to consideration of in-vessel retention-RPV. In this situation, the amount of water released to the CNV floods the outside RPV wall to a level that provides efficient cooling of any core debris in the RPV lower head.
- low core power density. The relocated core debris in the RPV lower head has lower volumetric heat generation rate than typical currently operating plants. This is because the NPM has much lower power density and takes a relatively long time to reach core relocation in a severe accident, allowing a significant decrease of decay power.

RAI 19-26

- small amount of fuel materials~~:~~.The amount of fuel materials is relatively small so that the core debris ~~pool~~ has a larger surface area to volume ratio than typical currently operating plants. Thus, the core debris has a large heat transfer surface relative to volume.

RAI 19-26

In summary, in a core damage event, the NuScale design ~~allows~~assures retention of the damaged core inside the reactor vessel. If containment isolation is successful, there is sufficient water retained in the CNV to provide a continuous, passive heat conduction and convection path from the damaged core to the UHS. Because ~~the failure of in-vessel retention-RPV~~failure to retain core debris in the RPV after a core damage accident involving an intact containment is not physically realistic, failure of the RPV is not included in the containment event tree.

19.2.3.2.2 Core Damage Progression with Retention in the Containment Vessel

RAI 19-26

The NuScale design of a vessel (i.e., RPV) within a vessel (i.e., CNV), combined with the relatively small core size and low power density, ~~make it virtually certain~~indicate that a damaged core would be retained in the RPV for severe accident sequences in which the CNV is intact. As stated in Section 19.2.3.2.1, if the containment barrier is intact such that RCS water lost in a severe accident is retained in the CNV, there is a continuous, passive heat conduction and convection path to remove heat from the damaged core and transfer it to the reactor pool. Thus, retention of core debris within the RPV after a severe accident is ~~the expected condition. However, to account for potential uncertainty in modeling of the severe accident progression, cooling and retention of core debris relocated to the lower head of the CNV from a failed RPV is evaluated.~~assured. However, for the benefit of demonstrating defense-in-depth with respect to the severe accident mitigating capabilities of the NuScale design, a discussion of the IVR capability of the CNV lower head is provided.

RAI 19-26

Drawing on similarities with the evaluation of core relocation in the RPV, evaluating the possibility of arresting core damage progression in the CNV is based on an analysis approach similar to that used for RPV retention. In both situations, as illustrated in Figure 19.2-7, core debris ~~is relocated to the lower head of a concave vessel and the concern is that the head fails due to thermal attack from the debris~~relocates to the lower head of a concave vessel with the potential to thermally challenge the lower head.

Evaluation of Core Debris Configuration in the Containment Vessel

As was the situation with the core debris configuration in the RPV, core debris that is hypothetically relocated to the CNV is a self-heating body assumed to be shaped by the geometry of the CNV lower plenum. The average heat flux from the core debris is maximized when the core debris consists only of fuel materials; i.e., the greater the amount of non-heat generating materials that are in the core debris, the smaller the average heat flux over the debris surface.

RAI 19-26

As illustrated in Figure 19.2-7, the core debris is submerged in water for severe accident sequences involving an intact containment. The water pool overlying the core debris precludes the possibility of the focusing effect as a highly conductive molten metallic layer on top of the oxidic debris is not possible given effective upward boiling heat removal. Even in the postulated scenario that a stable insulating vapor blanket forms over the debris and allows for a molten metallic layer, the heat removal from the top of the layer by radiation alone would mitigate a potential focusing effect. As such, the focusing effect is judged not to be a physically realistic challenge to in-vessel retention in the CNV.

RAI 19-26

~~The analysis of core damage retention in the RPV demonstrated that the heat flux profile associated with solid core debris presents more of a retention challenge than molten debris. Similarly, the evaluation of debris retention in the CNV assumes a solid core debris configuration. The configuration may be either a relatively uniform mix of metallic and oxidic materials or an oxidic volume with a metallic layer over its top. If the core debris is submerged in water, as it is in the scenarios relevant to retention of core debris in the containment vessel (in-vessel retention-CNV), a molten metallic layer is not possible. As stated above, ignoring metallic mass in the core debris results in the maximum volumetric heat generation rate, and hence maximum heat flux, from the core debris.~~

Basis for Evaluating Core Debris Retention in the Containment Vessel

RAI 19-26

Similar to the in-vessel retention-RPV analysis, the empirical CHF estimates derived from the SBLB tests are judged appropriate for the CNV lower head. While the region underneath the CNV lower head confined by the support skirt and the reactor pool floor differs from the open pool of the SBLB experiments, these geometric differences are judged not to have a significant effect on the CHF because the space underneath the CNV lower head is sufficient to accommodate the open pool boiling two-phase boundary layer. By extension, the open pool boiling CHF estimates derived from the SBLB tests are judged to remain appropriate for the CNV bottom head.

RAI 19-26

~~As illustrated in Figure 19.2-7,~~As previously discussed, the core debris in the CNV lower head is submerged in water, so heat removal from the top surface of relocated core debris in the CNV is greater than in the RPV situation. Additionally, the same debris mass has a greater surface area and thinner body in the CNV due to the ~~smaller~~lesser curvature of the CNV lower head (i.e., larger radius). These factors reduce the steady-state heat flux imposed on the CNV lower head and improve the core debris coolability in comparison to the RPV configuration. Because the CHF was not exceeded in the RPV ~~analyses~~analysis, it is also not exceeded for the CNV in a location that is in contact with the pool water.

Evaluate Potential Containment Vessel Failure

RAI 19-26

The CNV lower head has two parts, the curved cap of the vessel and an exterior, structural cylindrical skirt as illustrated in Figure 19.2-8. The space directly under the cap enclosed by the skirt is referred to as the "skirted region." To allow for exchange of coolant flow between the skirted region and the UHS residing outside the skirt, there are numerous large slots evenly spaced just below the joint where the skirt and the cap meet, and numerous small slots also evenly spaced just above the bottom of the skirt. If core debris is in the CNV lower plenum, water in the skirted region is heated and steam is generated. The slots provide pathways for steam generated inside the skirt to escape and for the water outside to flow in. The joint where the skirt and cap meet is designed with a small fillet region directly above the larger skirt slots, which is expected to accumulate a small amount of vapor that cannot be vented by the slots. Because ~~the heat flux profile is expected to take a bell-shaped curve with significant reduction at the fillet region, the small steam layer at this location is not expected to cause significant local heatup~~the steam layer blankets a small region of the CNV lower head compared to the thickness of the vessel wall, the local heat transfer degradation is not expected to cause significant local heatup as heat conducts to the well cooled proximities.

RAI 19-26

The CNV lower head integrity remains coolable as long as the slots provide a sufficient pathway for vapor escape, such that the small vapor region in the fillet does not grow and cause the lower head to exhibit significant dryout conditions and local overheating. Thus, the CNV lower head integrity is challenged only if the holes on the skirt fail to provide sufficient pathways for the steam generated in the skirted region to escape freely. ~~If a large vapor layer were to form over a significant area of the CNV lower head outer surface in the skirted region, the decrease in local heat removal efficiency could result in local overheating of the CNV lower head shell leading to a potential CNV lower head failure.~~

Summary of Analysis Results

RAI 19-26

The analysis is based on hand calculations to estimate the volume of steam generated inside the skirted region under the CNV lower head, with the boundary conditions obtained from MELCOR simulations. In the simple analytical model, with a given steam generation rate and a conservative loss coefficient through the slots, the height of the steam layer in the skirted region relative to the top of the upper slots is calculated. Assumptions for the most conservative sensitivity case were applied as follows:

- The decay heat load on the CNV lower head is selected based on a combination of 92 percent UO_2 relocation with no relocation of metallic materials and conservatively rapid time to core relocation.

RAI 19-26

- Energy required to bring the subcooled reactor pool water to the saturated condition is ignored.

RAI 19-26

- Heat loss ~~from the outflow of steam and~~ through the skirt is ignored.

RAI 19-26

- Heat flux from the top of the core debris is eliminated (~~signifying~~representing no coolant in the CNV), resulting in the highest possible heat flux to the CNV lower head.

RAI 19-26

In this most conservative sensitivity case, the height of the steam-trapped fillet region under the skirt is increased from 1 inch to 1.496 inches, and using more realistic relocated mass and heat transfer from the top of the debris, the height increases to 1.233 inches. This is a minimal increase, especially compared to the CNV vessel thickness of 3 inches. As a result of the configuration of the slots in the skirt, a natural circulation flow will develop with liquid flow entering the skirt from the bottom slots and a two phase liquid and steam flow exiting through the top slots. Because of the stable two-phase flow out of the top slots, the free flow of steam from the skirted region is unimpeded by recirculating or counter current flows.

RAI 19-26

The analysis conclude~~d~~s that the minimal steam accumulation in the skirted region ~~for all cases~~ does not lead to significant ~~heatup~~dryout of the CNV lower head, therefore melt-through or structural failure is not physically realistic. Thus, the CNV would retain core debris in the event of RPV failure.

Although not physically realistic and not explicitly modeled, if the CNV bottom head were to fail, potential consequences would be mitigated because the radiounclide release would be scrubbed by the reactor pool water.

19.2.3.3 Severe Accident Mitigation Features

Features that mitigate a potential severe accident are summarized in this section. The potential for cooling the RPV from the outside is facilitated by the containment design as discussed in Section 19.2.3.3.1. Section 19.2.3.3.2 through Section 19.2.3.3.6 address the capability of the NuScale design with respect to potential containment challenges if core debris is not retained in the active core region of the RPV in a severe accident. Section 19.2.3.3.7 deals with other potential mitigation features and Section 19.2.3.3.8 addresses equipment survivability in the CNV during a potential severe accident. Because of unique characteristics of the NuScale design, the only physically realistic mechanism for failure of the containment function is containment bypass or failure of containment isolation.

19.2.3.3.1 External Reactor Vessel Cooling

In the event of a severe accident with associated core damage, external reactor vessel cooling refers to the capability of cooling a core debris bed retained in the RPV by means of heat conducted through the RPV wall. The NuScale design with its small core, low power density and large surface-to-volume ratio facilitates external RPV cooling. Additionally for all intact containment accidents, coolant is retained in the CNV, surrounding the RPV vessel. The result of these features of the NuScale design is that retaining core material in the RPV is the only physically realistic end

Enclosure 3:

Affidavit of Zackary W. Rad, AF-1017-56517

NuScale Power, LLC
1100 NE Circle Blvd., Suite 200 Corvalis, Oregon 97330, Office: 541.360.0500, Fax: 541.207.3928
www.nuscalepower.com

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 specific NuScale design values.

   NuScale has performed significant research and evaluation to develop a basis for this specific NuScale design values 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. 161, eRAI No. 9043. 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 10/10/2017.

Zackary W. Rad