Supervisor's evaluation

I have reviewed the non-concurrence and my evaluation is below relative to each aspect detailed in the non-concurrence:

1. Phenomenon Identification and Ranking Table;

The non-concurrence states that there are dilution mechanisms not evaluated by NuScale, and attributes this to late identification of boron dilution in the PIRT process. The dilution mechanisms noted are: CVCS system operation post-ECCS (spray or lower riser injection) and manometer flow oscillations under low pressure and temperature.

I am aware that NuScale did note deficiencies in implementation of the PIRT recommendations and that there were [[ ]], as this was noted by NuScale as one of the apparent causes in their condition report written on February 27, 2020 (which the staff audited), following ACRS meetings noting the downcomer dilution phenomena. Subsequent to the identification of the errors noted in that CR, NuScale performed analyses and evaluations and assessed the LOCA break spectrum, non-LOCA events, LTC and the PRA. Therefore, although I agree that the identification of these mechanisms was late in the process, ultimately resulting in a CR, the analyses and evaluations were carried out by NuScale and evaluated by both the Reactor Systems and PRA staff in developing the draft SERs for Chapters 6, 15 and 19. My specific comments related to CVCS operation and manometer flow oscillations are provided under items 2 and 4 below.

2. System Vulnerability and Sensitivity to System Disturbances;

The non-concurrence states the system becomes vulnerable to any disturbance following ECCS operation due to the presence of a large volume of diluted fluid in the downcomer and lower plenum that can be transported into the core through nonsafety system injection, manometer oscillations or flow instability.

I agree that with extended ECCS operation, the downcomer and lower plenum will become diluted over time, since the collapsed liquid level following ECCS actuation is below the riser holes. NuScale evaluated, and the staff reviewed, the extent of such dilution over the 72 hour design basis mission time, and the impact of various potential disturbances. My comments related to the specific items noted as potential disturbances that could result in transport of diluted fluid from the downcomer and lower plenum through nonsafety system injection are under item 4 below.

Potential disturbances absent nonsafety system injection, such as manometer oscillations or flow instability, were explicitly considered in the evaluations conducted by NuScale, as well as staff evaluations. The staff considered both the potential for manometer oscillations induced by instability effects from flashing or geysering effects from steam condensation in the riser.

With respect to manometer oscillations induced by flashing, NuScale's evaluation that was available for staff audit determined that manometer oscillations, if they occurred, would be beneficial in promoting mixing between the core and lower plenum, and could therefore mitigate the downcomer dilution. This mixing was not credited by either NuScale or the staff.

With respect to manometer oscillations induced by geysering, NuScale's evaluation determined that there was a low temperature difference between the riser and downcomer, such that conditions are not conducive to large condensation with bubble collapse that would drive flow instability. The staff from RES independently (ML20183A149) looked at the potential for this phenomenon, and determined that geysering only had the potential to result in short-term power pulsing that would not damage fuel from either CHF or PCMI (this is also referenced in the staff's SER). The RES evaluation considered that condensation that could induce geysering could only occur at the non-boiling height of the downcomer and below, as above that level there is insufficient heat removal across the riser wall to induce sufficient condensation to result in geysering. RES staff looked at the TRACE-predicted temperature difference between the riser and downcomer, calculated the associated shrinkage rate from condensation, converted it to a flow rate, and determined the maximum reactivity insertion from this flow increase. The result was deemed a trivial shrinkage amount, resulting in a flow increase that would not likely be noticeable, and not challenge any fuel integrity limits.

I agree with these staff assessments that determined there is not any resulting safety issue from manometer oscillations induced by either flashing or geysering.

3. Event Trees and Events Involving System Disturbances;

The non-concurrence states that the event classification in 15.0.0.6.3 and 15.0.0.6.4 missed inclusion of non-safety system operation (CVCS injection through spray or riser injection; or CFDS injection) during the progression of PAs and AOOs.

The non-concurrence further states that NuScale identified use of CVCS to respond to small leakage events and asserts it was the availability of CVCS that motivated staff to relax acceptance criteria for leakage events below the LOCA spectrum and recommend approval of the GDC 33 exemption although confirmatory analysis showed the riser holes could become uncovered. The non-concurrence states that if operation of CVCS could be part of the event progression or credited by NuScale, then it should be evaluated in the analysis of these events, including the adverse impact on ECCS performance.

The event classification in DCA Part 2 Tier 2 Sections 15.0.0.6.3, "Engineered Safety Features Characteristics" and 15.0.0.6.4, "Required Operator Actions" were evaluated by Reactor Systems staff in draft SER section 15.0.0.6.3, "Treatment of Systems that are Not Safety-Related." Neither CVCS nor CFDS is credited in mitigating a design basis event, and therefore the staff found in its draft SER that treatment acceptable. The assertion in the non-concurrence that CVCS is credited

for small leakage GDC 33 events is not accurate. NuScale's GDC 33 exemption request in DCA Part 7, Section 5, as well as the description in DCA Part 2 Tier 2, Section 6.3, both specifically state that makeup is not relied on. NuScale did present rationale to the staff during its audit on May 11, 2020, that an operator would be following the TS actions for leakage and this would be managed operationally. NuScale proposed a safe shutdown type of analysis (which uses nominal conditions). However, the staff did not agree, and requested NuScale provide analyses of these events without credit for CVCS or operator actions, and considering uncertainties. This is reflected in a letter to NRC (ML20149M119) from NuScale. The staff's review of these analyses is in Section 6.3 of the draft SER.

These analyses evaluated multiple aspects of such events, including the potential that the riser holes could become uncovered prior to ECCS operation. NuScale determined the holes would not become uncovered prior to ECCS actuation for all scenarios. Because the staff did not agree with all aspects of the NuScale analysis, the staff did its own analysis, and did find one scenario where the holes could uncover (with pool temperature at the lower TS allowable value (65 degrees vs. 100 degree nominal) and a 0.9% CVCS discharge line break where the ECCS valves repositioning based on local dp across the main valve bodies, also considering the most adverse tolerance for the valves). In considering this scenario, though, the staff did ultimately exercise discretion in that the scenario included the worst set of assumptions, and in consideration of this, the staff credited in its evaluation that there would be available shutdown margin if the stuck rod was not considered. Since the analysis was performed for evaluation of an exemption, the staff determined, and I agree, that the decision to consider available shutdown margin was appropriate considering the likelihood of the very specific combination of events making up the scenario where shutdown margin was credited.

This evaluation did not in any way consider use of CVCS or credit CVCS, and the use of CVCS is in no way part of the event progression. Further, CVCS isolates on pressurizer level, and dilution of the downcomer, and any associated challenges with starting CVCS flow, would only commence once the riser holes become uncovered. The elevation of the riser holes is below the elevation where CVCS would automatically isolate. Restoring CVCS to operation following an isolation would take a deliberate operator action with multiple steps. This places this type of operator action outside the single failure requirements for Chapter 15 analyses, as any action to inject with a system such as CVCS during a time when such injection would be detrimental and as such would be considered an error, since operational procedures completed by an eventual COL holder would not instruct an operator to initiate a system when such operation would be unsafe, and it would therefore also not be part of the event progression. Since that type of error would require multiple deliberate operator actions (see draft SER section 18.10.4.4.2.4.2), it is not considered within Chapter 15 analyses.

4. <u>Design Basis Events and Long-Term Cooling Without Non-safety System Operations</u>;

a. The non-concurrence states that, according to NuScale's response to RAI 8930, several hours after ECCS operation most of the boron has migrated to the core and lower riser, and the boron concentration is close to zero in the downcomer, lower plenum and the volume above the RRVs in containment. It also states that NuScale assumed [[ ]], and therefore concluded there was no dilution in the core. It states that the non-concurring individual performed an analysis where 95% of the borated fluid returns to the core and that with that assumption the reactor would return to criticality after 9 hours with one stuck rod, and 20 hours with all rods in. It further states that the [[ ]] assumption is non-conservative.

   I understand Dr. Lu's concern in the statements above to be related to the potential that the upper riser boron concentration could be higher than the core concentration, and that could potentially result in the core returning to power. The data from the VEERA tests clearly demonstrate that above the boiling elevation, the boron in the core is well mixed, and a 100% mixing assumption is appropriate within the core. My staff reviewed the VEERA test data, held discussions with NuScale staff via audit in Corvallis in October 2019, and discussed the testing setup with NuScale at length during those discussions. I agree that the test data showed essentially no difference in boron concentration once above the boiling boundary (see page 55 of the response to RAI 8930), justifying a [[ ]]. With respect to the riser/core mixing, during that audit, my staff looked at NIST-1 void fraction data and determined that, similar to the boiling in the core (caused by heat flux), that void generation would promote mixing between the core and riser. I agree with this conclusion. Further, the staff had NuScale perform an MCNP calculation assuming [[ ]], even though the VEERA data showed mixing between the core and lower plenum. This conservative assumption of [[ ]] was used by NuScale to perform a criticality analysis, which demonstrated subcriticality. Much of this is described in summary format in the staff's draft SER, section 15.0.6.

b. The non-concurrence further states that NuScale responded to the concern about the 100% mixing assumption by using test data from VEERA to show that there is a lower boron concentration below the boiling length. The non-concurrence provides a variety of concerns relating to inapplicability of the boiling length shown by VEERA since the NuScale reactor has different dimensions. The non-concurrence concludes that use of the VEERA data to determine the non-boiling length in the NuScale reactor is therefore non-conservative.

   The VEERA data was not used to determine the non-boiling length for the NuScale design. The VEERA data was only used as an experimental demonstration that above the height where boiling commences, the boron is well mixed. Therefore, for the purpose that the VEERA data was used, any scaling distortions are irrelevant. The NuScale non-boiling length was instead determined as described in NuScale's response to RAI 8930, page 67, with information directly from NuScale NPM specific analyses. These analyses were reviewed in detail by Reactor Systems staff, as described in draft SER section 15.0.6, and I agree with

their finding that there is reasonable assurance that this non-boiling length is conservative.

c. The non-concurrence states that the German Volatility correlation (Böhlke) is not scalable to the NuScale design, based on its data being collected at the BORAN facility with very different heated lengths and mass flowrates. It further states that the correlation predicts a lower value for volatility by a factor of 2.0 compared to WAPD data and data published in the 1999 Chemical Thermodynamic Journal. The non-concurrence states the staff performed sensitivity analyses that showed a return to power within 72 hours once other volatility correlations are used.

The appropriateness of use of the Böhlke correlation is documented in the staff's draft SER, section 15.0.6.4, and the staff's evaluation considered its development from data from the BORAN facility, as well as other volatility data in available literature, including both the WAPD data and the Kukuljan, et. al. data published in the 1999 Chemical Thermodynamic Journal. Details are also discussed in NuScale's response to RAI 8930, pages 21-36. Reactor Systems staff and I participated in a detailed audit in October 2019 in Corvallis, OR, and many of the issues the staff brought up in that audit were documented and dispositioned in that RAI response.

First, with respect to use of the BORAN facility, the BORAN facility was used to collect data to correlate void fraction (as a surrogate for interfacial area and contact time) with volatility. The other factors impacting volatility and calculated by using the correlation (pH, chemical species, temperature, concentration) were developed from autoclave data. However, with respect to the void fraction dependency and its development from BORAN data, NuScale did assess the key parameters associated with the BORAN facility vs. the NPM (see page 22 of NuScale's response to RAI 8930).

For the parameters where there is a difference between the BORAN facility and the NPM, the RAI response assessed those differences in consideration of further elaboration of the development of the Böhlke correlation provided in the dissertation. The mass flux is different between the NPM in ECCS mode and the BORAN facility, in that it is much less. However, prior to ECCS actuation, the NPM's flow rate is much higher. Higher mass flowrates generally increase the interfacial area, since higher flowrates break up large bubbles into smaller bubbles. NuScale assessed the specific flow regimes present in the BORAN facility and the NPM and determined that use of the Böhlke correlation was conservative relative to the much lower predicted mass flowrates for the NuScale NPM. NuScale investigated the impact of this portion of the volatility calculation by looking at the change in volatility from increases in mass flow rate in BORAN experiments. Because of the higher mass flowrates in the BORAN experiments,

the predicted volatility for a given void fraction would be predicted higher, since the interfacial area would be higher in BORAN. NuScale did not credit this conservatism, and in addition applied an additional [[ ]] factor for uncertainties to the Böhlke correlation. The detailed rationale for the flow regimes in BORAN vs. the NPM during blowdown and long-term ECCS cooling is documented on page 24 of the response to RAI 8930. Reactor Systems staff reviewed this assessment and found it acceptable, and I agree with this assessment.

The figure provided in the non-concurrence, Figure 6, includes data from multiple sources, as well as data with different chemical species and pH values. Because volatility is dependent on all of these factors, this figure, as presented, shows a variety of measured data for a variety of conditions that would be expected to produce very different volatilities. Reactor Systems' staff, through its audit, requested NuScale to evaluate the use of the Böhlke correlation, in consideration of other measured data, including many other data sets in addition to the WAPD and 1999 Kukuljan, et. al. data. Pages 25-30 of the response to RAI 8930 document this assessment, and Figures BV-3 through BV-5 show the comparison of the Böhlke predictions for the various conditions in the experiments to the recorded data. The Böhlke predictions show good agreement with the measured test data, with the exception of the low temperature range of the two specific sets of data noted in Dr. Lu's non-concurrence, which were dispositioned by NuScale as representing theoretical maximum volatility rates at fully equilibrium conditions. In contrast, at low temperatures, the NPM is not expected to approach equilibrium conditions. The staff, in its draft SER, agreed with this assessment, based on its review of the test data and the test setups, and the applicable NPM operating conditions, that these two sets of data need not be bounded for the correlation to be conservative for the NuScale design since the portions of data that the correlation does not bound are not relevant to the NPM operating conditions.

The applicant also conducted an additional margins assessment to consider a higher level of uncertainty in the volatility rate and determined that a significantly higher ([[ ]] times higher) volatility could be tolerated during the 72 hour period, and the final boron concentration in the RCS would still not drop below the initial boron concentration. Although this does not bound the 2 data sets Dr. Lu cites, those data sets are not representative of the NPM conditions, as noted previously. This additional margin to the rest of the data sets that are applicable is substantial, more than providing reasonable assurance in the applicability of the correlation. Beyond this, the applicant also did not consider that any of the volatized boron that had plated out re-dissolves into the coolant. I agree with the staff's assessment that there is reasonable assurance that the use of the volatility correlation selected by NuScale is conservative.

d. The non-concurrence states that although there are other conservatisms in the methodology, both the non-boiling length determination and the volatility correlation are major uncertainties, and therefore the overall conservatism of the approach cannot be proven, and as such there is not reasonable assurance that there will not be a return to power with boron in the RCS.

   I disagree that the approach cannot be proven to be overall conservative and that there is not reasonable assurance for the staff's findings. As stated above, I agree with the staff's findings in its draft SER, section 15.0.6, that both the volatility correlation and non-boiling length determination are appropriate and that the staff therefore has reasonable assurance in the conservatism of the methodology as a whole.

5. Design Basis Events and Long-Term Cooling With Non-safety System Operations;

The non-concurrence states that staff calculations were performed for a CVCS line break with initiation of various non-safety injection scenarios 1 hour after ECCS operation commenced, resulting in a surge of colder water into the core.

The initiation of non-safety injection is not within the required scope of Chapter 15 analyses. As stated under item 3, CVCS operation would require multiple deliberate operator actions to initiate and operate, following its isolation, placing its post-event use outside of consideration in Chapter 15 analyses. Similarly, initiation of the Containment Flood and Drain System (CFDS) requires multiple deliberate operator actions that place its startup and operation outside of Chapter 15 analyses. In both cases, these would be considered operator errors, for the reasons described under item 3. Consideration of these potential operator error sequences is included in the DCA under the PRA review. The staff's evaluation of the PRA considered these sequences. The staff's evaluation leveraged independent work performed by RES (ML20183A149).

For injection via pressurizer sprays, the non-concurrence states that this could result in $21 of reactivity over 60 seconds, which could lead to core failure. For injection via containment flood and drain, the non-concurrence states that $21 would be injected into the core over 15 minutes, which would return the core to power with all rods in and has not been analyzed. For injection via CVCS into the riser, the non-concurrence states that an RES hand calculation demonstrates a surge will enter the core, and an NRELAP5 calculation shows significant manomentric oscillations with a return to power with or without a stuck rod and states additional studies are needed.

The non-concurrence states these scenarios can be so severe that core damage is expected, and have not been analyzed by NuScale as part of long-term cooling. It further states that the CDF could be in the range of 3.3e-5 to 3.3e-7.

These event sequences are not part of the Chapter 15 required analyses, for the reasons stated previously. The independent evaluation performed by the Office of RES (ML20183A149) considered each of these scenarios to support the staff's review of the NuScale PRA, and the Chapter 19 SER that considered this independent work was concurred on by PRA staff and management. The description that follows is a summary of this evaluation from the PRA staff.

In this independent evaluation, the Office of RES evaluated the sequence of events for the worst case SBLOCA-ATWS to determine which conditions and phenomena could produce the potential for a core flow surge to yield core damage as a result of a super prompt reactivity excursion. The staff conducted a thorough review of the possible phenomena and processes that could lead to rapid flow incursions. The staff then screened those possible incursions to determine which might have the possibility of producing an adverse power excursion. Level Swell from CVCS Injection into the Riser under very specific circumstances, injecting water into the riser through the CVCS may cause rapid condensation of the void in the riser section. This condensation can cause shrinkage and local negative pressure, which in turn causes a flow surge. The staff's hand calculations indicated that this mechanism could possibly cause a prompt reactivity excursion. However, the set of circumstances necessary to produce this outcome are highly unlikely. Further, the staff could not reason what process or phenomenon could preclude the development of internal recirculation in the NuScale power module. The staff's literature review indicated experimental evidence in large diameter pipes, bundles, scaled reactor coolant system geometries and even under adiabatic conditions. These tests appear to show the consistent evolution of internal recirculation in pool boiling conditions. While this appears to be the main point of contention, the staff concluded that such internal recirculation is a genuine physical phenomenon and that it could be reasonably expected to occur in the NuScale power module during the postulated events.

The specific set of circumstances where the CVCS injection could lead to a possible flow incursion with severe reactivity consequences include: (1) a SBLOCA must have occurred, (2) the control rods fail to insert and operators are unsuccessful at inserting the rods through other means (e.g., deenergizing the solenoids), (3) the ECCS valves fail to operate on demand, but somehow the operators are successful through other means in depressurizing the RPV (e.g. 50 psia), and (4) noting a large discrepancy in boron concentration in the riser and downcomer, the operators align the CVCS for riser injection at a high flow rate versus the nominal flow rate of 22 gpm. This operator error would be expected to be inconsistent with the plant-specific EOPs given that NuScale modified DCA Part 2 Tier 2 Chapter 4 and Section 15.0.4 to indicate recovery from passive cooling needs to take into consideration the boron dilution potential and ensure shutdown margin requirements are met. In summary the PRA staff concluded from this independent evaluation that this specific sequence would be highly unlikely when compared to the very low NuScale core damage frequency. Furthermore the independent evaluation states that even a partial rod insertion is likely to ensure some net negative reactivity worth at the start of the flow incursion and this would probably be enough to preclude prompt criticality.

6. Beyond Design Basis Events and Shutdown Operation.

a. The non-concurrence states that Chapter 19 event trees and sequences did not account for either adverse non-safety system operation or boron dilution, and that consideration of these would change the overall risk profile.

I agree that the initial PRA, as submitted, did not consider boron dilution. However, in reaching its final safety finding, the staff's Chapter 19 review did consider adverse non-safety system operation and boron dilution from operator errors, as described under item 5, above, and determined the design would meet the Commission's Safety Goals. Regarding boron redistribution and non-safety system operation, the PRA staff concluded that the DCA Chapter 19 risk results and insights were appropriately updated so that staff could finalize their safety findings consistent with SRP 19.0.

b. It further states that NuScale has claimed non-safety system operation should be part of post-ECCS recovery operation governed by EOPs developed by COL applicants.

NuScale's procedures for use of non-safety systems to recover a module were not part of the DCA review. The staff did not make a finding or give finality to the Generic Technical Guidelines. Consideration of procedures occurs in later stages of the licensing process, not the DCA review.

c. The non-concurrence further states that NuScale requested relaxation of requirements for small leakage events in its GDC 33 exemption and claimed the operator can take action to mitigate the boron dilution, which is inconsistent with the prior statement.

Further, as I described under item 3, the staff did not relax its requirements for small leakage events in considering the GDC 33 exemption, and did not in any way consider mitigation by the operator using CVCS.

d. It further states that if a recovery scenario can result in a return to power with all rods in, it should be treated as an extension of the AOO or PA and evaluated in Chapter 15. It notes the GDC 27 exemption does not permit a return to power with all rods in.

I also previously addressed the consideration of recovery actions relative to Chapter 15 requirements under item 5, above, as being outside the scope of Chapter 15. That also then places such scenarios outside the requirements of PDC 27, which specifies the reactor be designed such that it does not return to power with all rods in during a design basis event.

e. It further states that early in core life, these scenarios can result in core damage, and there may not be a reasonable recovery capability.

I addressed the potential for core damage under item 5, above. Although recovery procedures are not required at the DCA stage, NuScale did make some conceptual recovery options available for staff audit. Further, based on interactions with reactor systems staff, NuScale modified DCA Part 2 Tier 2 Chapter 4 and Section 15.0.4 to indicate recovery from passive cooling needs to take into consideration the boron dilution potential and ensure shutdown margin requirements are met. In reaching my decision on approval of the SER, I consider the inclusion of those statements, and the staff's language in the SER, sufficient to highlight to a future COL that operational procedure development needs to account for this boron dilution potential. Should a COL determine that a design change is desirable to reduce the complexity of recovery actions, a design change could be sought at that time through the departure process.

f. The non-concurrence goes on to propose a design modification to add a passive boron injection system, which it states could be added within the current review schedule.

It is not the role of the NRC to propose or mandate a specific design change to an applicant where there are multiple potential options for meeting the regulations. In this case, for the reasons set forth in the staff's draft SER, and as reflected in my evaluation above, I do not agree that a passive boron injection system is required or necessary.