UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, DC 20555 - 0001

July 29, 2020

Ms. Margaret M. Doane
Executive Director for Operations
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT: NUSCALE AREA OF FOCUS – BORON REDISTRIBUTION

Dear Ms. Doane:

During the 674th, 675th, and 676th meetings of the Advisory Committee on Reactor Safeguards, June 3-5, 2020, July 8-10, 2020, and July 21-24, 2020, we continued our boron redistribution area of focus review for the NuScale Power, LLC (NuScale or applicant), design certification application (DCA) as discussed in our April 29, 2020 letter. We reviewed the staff's evaluation of NuScale's, "Submittal of Second Updates to NuScale Power, LLC Standard Plant Design Certification Application, Revision 4." During this meeting, we had the benefit of discussions with NuScale and the staff. We also had the benefit of the referenced documents. A finding relative to the requirements of Title 10 of the *Code of Federal Regulation* (10 CFR) 52.53 awaits completion of our review.

CONCLUSIONS AND RECOMMENDATIONS

1. NuScale has incorporated design and setpoint changes to the NuScale Power Module (NPM) to mitigate the effects of boron dilution in the downcomer for design basis uncontrolled passive cooling events and loss-of-coolant accidents (LOCAs) up to the time of emergency core cooling system (ECCS) actuation.

2. The applicant has demonstrated for these scenarios, through a conservative analytical approach, that the design modifications maintain the boron concentration in the downcomer above the critical boron concentration level necessary to prevent recriticality and a return to power. The staff's evaluation confirms the applicant's analyses out to 72 hours.

3. However, ECCS actuation events result in water levels below the new riser holes and render them ineffective; thus, coolant in the downcomer will deborate for a range of design basis accidents, including small-break LOCAs. The estimated time for the boron concentration to drop below the critical boron concentration in the downcomer for these events is within a few hours.

4. Operator recovery actions raise the possibility of an influx of deborated water into the core, which may result in recriticality, return to power, and the potential for core damage.

5. Detailed operator response and recovery procedures will be developed by the combined license (COL) applicant. The staff must ensure that these recovery strategies will prevent core damage with a high degree of confidence.

6. A focused effort by the COL applicant is needed to develop recovery strategies that will lead to effective operating procedures. Given the inability to measure the distribution of boron in the NPM during these events, these strategies should have a stronger technical basis than is currently documented that demonstrates a path to successful recovery to prevent core damage. The probabilistic risk assessment (PRA) should be updated accordingly at the COL stage to appropriately reflect the risk of boron dilution events, including associated operator actions.

BACKGROUND

The potential for boron dilution to occur in the downcomer of the NPM under design basis event conditions, for both anticipated operational occurrences and design basis accidents, was raised during our area of focus review of boron redistribution. This occurs when the NPM riser is uncovered, interrupting natural circulation flow during passive cooldown transients or LOCAs. In these transient and accident conditions, boiling will cause distillation leading to condensation of the steam in the downcomer, which dilutes the concentration of boron over extended periods of time. In March 2020, NuScale determined that, under some conditions, the downcomer may deborate before the ECCS valves actuate, at which time a large ingress of water from the containment could push the deborated water in the downcomer into the core. This creates the potential for the reactor core to return to criticality and increase power with either the addition of makeup coolant water, or the reestablishment of natural circulation flow as the deborated water from the downcomer enters the core.

The applicant concluded that the associated risk was unacceptable, implemented corrective actions, and provided design modifications consisting of riser holes at the midplane level of the steam generators that maintain a flow of borated water to the downcomer, even if the riser is uncovered. Further, changes were made to ensure earlier ECCS actuation by adding a low reactor coolant system pressure setpoint and lowering the containment vessel level setpoint, hence preventing buildup of deborated water inventory in the downcomer at the time of ECCS actuation.

DISCUSSION

The applicant developed simple analytical bounding analyses to demonstrate that, for passive heat removal and small-break LOCA scenarios, the boron concentration in the downcomer remains above the critical boron concentration prior to ECCS actuation. These analyses show ample margin under the most limiting high boron concentrations at beginning-of-cycle and middle-of-cycle conditions. The bounding analyses demonstrated that the new riser holes provide for sufficient borated water flow to prevent deboration of water in the downcomer for scenarios in which the water level in the downcomer remains above the riser holes. The staff has audited these bounding calculations and found that recriticality is prevented for a period up to 72 hours.

However, for most LOCA and ECCS actuation events, once the riser holes are uncovered, the downcomer and lower plenum begin to deborate because of condensation on the steam generator tubes, the reactor vessel inner wall, and the containment wall. Also, for steam-space LOCAs (e.g., failure or inadvertent opening of an ECCS reactor vent valve), deborated water continues to accumulate in the containment. NuScale and staff calculations show that, after ECCS actuation, boron concentration in the downcomer could fall below the critical boron concentration within hours – a potentially metastable system configuration from a reactor physics standpoint. Should this colder, deborated coolant insufficiently mix as it reaches the core, there exists the possibility of a recriticality and return to power event. However, the staff has asserted that mixing will occur as the deborated coolant enters the core preventing significant power excursions. The staff assertion is based on three-dimensional TRACE calculations supported by open literature experimental data indicating internal recirculation occurs in pool boiling conditions with fuel bundle geometries similar to the NPM core.

Recovery of the NPM from this deborated downcomer condition to a long-term stable state that permits transport to the refueling station will eventually be required. Although other pathways may later be identified, the applicant has initially identified three pathways for adding borated water for recovery: 1) the chemical and volume control system (CVCS) injection line to the riser region above the core; 2) the CVCS pressurizer spray line above the downcomer; and 3) the containment flooding and drain system (CFDS) fill by means of the ECCS reactor recirculation valves. The first option is preferred; but we are concerned about potential design basis event scenarios where the CVCS injection line suffers a non-repairable failure (e.g. a LOCA inside containment) or is otherwise unavailable for injection. We also observe that neither the CVCS nor the CFDS was identified as risk-significant in Final Safety Analysis Report Chapter 19 or included in the Design Reliability Assurance Program.

The staff expects that return to criticality from a boron dilution event is highly unlikely. As part of their review, the staff performed an evaluation of the impact of possible deborated water ingress into the core. They concluded that there was no credible path to significant core damage under these conditions based on the physical effects of fluid mixing, reactivity feedback mechanisms, and associated time constants. This assessment was critical to the staff's reaching a reasonable assurance finding on the DCA.

We are not entirely convinced by the staff's arguments and conclusion. While a prompt critical reactivity excursion is unlikely, any appreciable return to power at essentially zero flow and low pressure could lead to voiding, power-induced flow oscillations, possible return to natural circulation by riser swelling, and excessive core heatup. This analysis is further complicated by the void reactivity coefficient for these reflooding events, which could be positive, possibly leading to a rapid power excursion.

The COL applicant must define the long-term recovery strategy from these events with a sound technical basis to document that a success path exists to recover from post-ECCS actuation. The staff's assessment presents a technical, but generalized, end-state analysis based on engineering judgment and informed by considerations of physical phenomena that could occur in these events. Application of best-estimate system calculations (e.g., three-dimensional, coupled thermal-hydraulic/neutronic-kinetics models) is warranted to best elucidate and properly inform specific recovery actions. We are concerned that no instrumentation is available to effectively measure boron redistribution; only a point measurement of downcomer boron concentration is possible. Uncertainties in other instrumentation (e.g., water level instrumentation) must be considered during the development of the recovery procedures. Approach to criticality might be inferred from neutron flux detectors, but these provide a weak means to avoid a prompt criticality event.

The PRA, as presented in Final Safety Analysis Report Chapter 19, does not capture the boron dilution related sequences and their consequences at this time. The COL applicant must develop operating procedures that ensure a successful recovery path for boron dilution events, with documentation of the underlying technical bases, and update the PRA, including human factor evaluations, to better reflect the impact of these scenarios on overall risk.

We look forward to reviewing boron dilution event recovery strategies once they are developed.

SUMMARY

A focused effort by the COL applicant is needed to develop recovery strategies that will lead to effective operating procedures. Given the inability to measure the distribution of boron in the NPM during these events, these strategies should have a stronger technical basis than is currently documented that demonstrates a path to successful recovery to prevent core damage. The PRA should be updated accordingly at the COL stage to appropriately reflect the risk of boron dilution events, including associated operator actions.

Sincerely,

Matthew W. Sunseri Digitally signed by Matthew W. Sunseri Date: 2020.07.29 09:12:14 -04'00'

Matthew W. Sunseri
Chairman

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