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

October 19, 2020

MEMORANDUM TO: Matthew W. Sunseri, Chairman,
Advisory Committee on Reactor Safeguards

FROM: Jose March-Leuba, Chairman,
Accident Analysis Thermal-Hydraulics Subcommittee

Jose A. March-Leuba
Digitally signed by Jose A. March-Leuba
Date: 2020.10.19 12:20:54 -04'00'

SUBJECT: BORON DILUTION EVENTS IN THE NUSCALE POWER MODULE – RECOMMENDATIONS FOR CONSIDERATION IN REVIEWING POSSIBLE ACCIDENTS FROM DEBORATED CONDITIONS

The purpose of this letter is to document recommendations by this ACRS member to evaluate the potential increase in risk created by boron dilution events in a NuScale Power Module (NPM). In completing our review of the staff's safety evaluation and the associated NuScale design certification application (DCA), ACRS documented concerns regarding transient and accident scenarios that may lead to metastable conditions characterized by diluted boron concentrations in the downcomer region of the primary coolant system. The analyses in the DCA demonstrated that, immediately following emergency core cooling system actuation with all rods in, the core remains covered and maintains a boron concentration sufficient to achieve subcriticality; however, a rapid insertion (caused by an accident or an operator error) of a large mass of cold deborated coolant from the downcomer leads to the potential for a reactivity insertion accident. Without detailed analyses of how the NPM might actually respond to accidents (e.g., operator errors or equipment failures) from this state, a potential return to power leading to fuel damage cannot be discounted a priori. The potential risk from this return to power needs to be evaluated before a combined license is issued.

Discussion

The Office of Nuclear Reactor Regulation staff, in its response to the ACRS letter report on the subject, "NuScale Area of Focus – Boron Redistribution," based its conclusions on two papers developed by the Office of Nuclear Regulatory Research. However, these results were not covered in detail in their safety evaluation report or their presentations to us. The ACRS position was to defer a thorough evaluation of these issues until after the balance of plant is fully designed. Once the balance of plant details are defined, the following items must be evaluated by the applicant and the staff should review them:

- The progression of boron dilution events all the way to a safe, stable condition (i.e., completion of the reflood stage to reestablish a coolant level in the pressurizer and reestablishment of natural circulation).

- All credible accidents that could be initiated from the deborated state. The DCA and the staff safety evaluation contend that these issues will be addressed after final operating procedures are developed. However, the risk posed by operator errors of omission or commission, or by inadvertent equipment actuations or failures must be fully evaluated before a combined license is issued.

When the analyses are carried to completion for most water level rising scenarios (either intentional via procedures or unintentional via operator errors or equipment failures), coolant will eventually overflow the top of the riser. This will increase the core inlet flow significantly and will likely reduce mixing with the highly borated coolant in the core region. If unmixed volumes of cold deborated water remain in the downcomer (e.g. in the steam generator region, where the equivalent diameter is small and axial mixing is difficult to envision), they may be swept rapidly into the core by the reestablished flow. These unmixed volumes may cause a return to criticality and power if they fail to mix adequately.

Looking ahead, there are at least three potential scenarios of concern that, to my knowledge, were not fully analyzed in the DCA:

1. According to the staff's safety evaluation report, if level rising is achieved by injecting water into containment (intentional or unintentional via errors or failures), return to power is possible. The resulting void fraction will swell the water level in the riser and may overflow to the downcomer. This would restore some degree of natural circulation, which may significantly increase the rate of insertion of unmixed volumes of deborated water from the downcomer into the core.

2. If level recovery is achieved via containment injection but the core remains subcritical because of adequate mixing in the core, eventually the riser water level will increase sufficiently to restore natural circulation. At this point, unmixed volumes of deborated water may remain in the downcomer, specifically above the reactor recirculation valve elevation, where it has been pushed up by the containment inflow and condensate continues to accumulate. These unmixed volumes of deborated water may be pushed into the core rapidly by the reestablished natural circulation, resulting in reduced mixing and possibly an unanalyzed return to power.

3. If borated water is exclusively injected into the riser region (e.g., if the letdown line is unavailable or its flow is insufficient), the level will rise, and some borated water will back flow to the bottom of the downcomer. The potential exists that unmixed volumes of deborated water will remain in the steam generator region. After natural circulation is reestablished when the water level reaches the top of the riser, a return to power cannot be discounted without further analysis.

Note that these scenarios are not an exhausting list of all possibilities, and others may exist.

Cronenberg provides an excellent compendium of boron dilution issues in pressurized water reactors. This reference provides a possible roadmap for the evaluation of NuScale issues. However, differences in design exist, and the frequencies and consequences evaluated for pressurized water reactors may not transfer directly to NuScale.

In summary, the NuScale passive cooling design may result in non-homogeneous boron concentration in the NPM under many scenarios. Unmixed volumes of deborated water may exist, especially in the steam generator. Most scenarios will eventually increase the riser water

level and restore natural circulation, creating the potential for deborated water to enter the core at high velocity. To my knowledge, most of these scenarios have not been evaluated by NuScale or the staff. It is reasonable to wait until the balance of plant components are fully designed before these scenarios can be accurately evaluated. But a combined license should not be issued without thoroughly reviewing the risk of these deborated conditions.

Recommendation

I recommend that the Committee provide this memorandum to file for future consideration by any future license applicant that references the NuScale standard design approval or certified design, and for any future review of such application by the staff and the ACRS.

References

1. Advisory Committee on Reactor Safeguards, “NuScale Area of Focus - Boron Redistribution,” July 29, 2020 (ML20210M890).

2. Advisory Committee on Reactor Safeguards, “Report on the Safety Aspects of the NuScale Small Modular Reactor,” July 29, 2020 (ML20211M386).

3. Advisory Committee on Reactor Safeguards, “Observations and Lessons Learned From ACRS Licensing Reviews Relevant to Future Advanced Reactor Applications,” October 2, 2020 (ML20267A655).

4. U. S. Nuclear Regulatory Commission, “Response to the Advisory Committee on Reactor Safeguards Letter on NuScale Power, LLC, Area of Focus – Boron Redistribution,” August 25, 2020 (ML20231A598).

5. U. S. Nuclear Regulatory Commission, “Response to the Advisory Committee on Reactor Safeguards Letter on NuScale Power, LLC, Report on the Safety Aspects of the NuScale Small Modular Reactor,” August 25, 2020 (ML20224A460).

6. A. W. Cronenberg, “Summary of Boron Dilution Issues and Regulatory Actions,” November 3, 2000 (ML082911010).

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