POLICY ISSUE
(Information)

May 8, 2019 SECY-19-0047

FOR: The Commissioners

FROM: Margaret M. Doane
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SUBJECT: CONTAINMENT PERFORMANCE GOALS FOR THE NUSCALE SMALL MODULAR REACTOR DESIGN

PURPOSE:

This paper informs the Commission of the U.S. Nuclear Regulatory Commission (NRC) staff's plans to address the new reactor containment performance goals in the review of NuScale Power, LLC's (NuScale) design certification application (DCA). Consistent with the objective of providing defense-in-depth for severe accidents, the staff intends to evaluate the NuScale design capability using specific alternative criteria related to the prevention of a large radiological release to the environment instead of in terms of a physical failure of containment. Consistent with SECY-10-0034,[1] the staff is informing the Commission of this issue during its evaluation of the design, prior to the design certification rulemaking process, in order to provide for more timely and effective regulation, minimize complexity, and add stability and predictability in the licensing and regulation of small modular reactor designs.

SUMMARY:

NuScale performed a severe accident analysis to show that molten core debris would be retained within the reactor vessel due to water in the containment cooling the reactor vessel outer surface, thus preventing a breach. However, severe accident phenomenological

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[1] SECY-10-0034, "Potential Policy, Licensing, and Key Technical Issues for Small Modular Nuclear Reactor Designs," March 28, 2010 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML093290268).

uncertainties associated with cooling molten core debris create analytical challenges for reviewing containment performance under the criteria used for previous new reactor reviews. Therefore, the staff plans to apply an alternative review approach by verifying that the NuScale design prevents a large radiological release to the environment. Through this approach, the staff will ensure that the NuScale design achieves the goals of containment performance by an alternate means and that this approach provides reasonable assurance of adequate protection of public health and safety.

BACKGROUND:

As discussed in the Commission's Severe Accident Policy Statement,[2] a new nuclear power plant design can be shown to be acceptable for severe accident concerns if it meets several criteria, including the completion of a probabilistic risk assessment (PRA) and consideration of the severe accident vulnerabilities that the PRA exposes. In this policy statement, the Commission also noted that some severe accident scenarios result in insignificant probability of offsite consequences because of containment effectiveness. Due to the importance of containment integrity for the protection of public health and safety, Title 10 of the *Code of Federal Regulations* (10 CFR), Section 52.47(a)(23) requires that DCAs include the following in their final safety analysis report (FSAR):

> *For light-water reactor designs, 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 core melt ejection, hydrogen combustion, and containment bypass.*

SECY-90-016[3] and the associated staff requirements memorandum (SRM)[4] established the core damage frequency and large release frequency goals of less than 10^{-4} per year and less than 10^{-6} per year, respectively, as a way to implement the objectives in the Commission's Safety Goal Policy Statement[5] regarding low risk to the public from nuclear power plant operation. SECY-90-016, SECY-93-087,[6] and the associated SRMs[7] also established the following containment performance goals as a way to demonstrate the acceptability of new reactor designs to mitigate severe accidents:

- The conditional containment failure probability (CCFP) should be less than 1 in 10 when weighted over credible core-damage sequences. This goal will maintain a balance between accident prevention and consequence mitigation.

- The containment should maintain its role as a reliable, leak-tight barrier for approximately 24 hours following the onset of core damage under the more likely severe

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2 "Policy Statement on Severe Reactor Accidents Regarding Future Designs and Existing Plants," 50 FR 32138, August 8, 1985.

3 SECY-90-016, "Evolutionary Light Water Reactor (LWR) Certification Issues and Their Relationship to Current Regulatory Requirements," January 12, 1990 (ADAMS Accession No. ML003707849).

4 SRM-SECY-90-016, June 26, 1990 (ADAMS Accession No. ML003707885).

5 "Safety Goals for the Operations of Nuclear Power Plants; Policy Statement; Republication," 51 FR 30028, August 21, 1986.

6 SECY-93-087, "Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced Light-Water Reactor (ALWR) Designs," April 2, 1993 (ADAMS Accession No. ML003708021).

7 SRM-SECY-90-016; SRM-SECY-93-087, July 21, 1993 (ADAMS Accession No. ML003708056).

accident challenges and, following this period, the containment should continue to provide a barrier against the uncontrolled release of fission products.

The purpose of these containment performance goals is to ensure that the design provides for defense-in-depth to mitigate the consequences of severe core damage accidents. In approving the CCFP performance goal in SRM-SECY-90-016, the Commission noted that the CCFP performance goal should not be imposed as a requirement. The Commission stated that staff could consider alternative containment performance objectives that provide comparable mitigation capability and, following the staff's review, submit them to the Commission for its consideration. The deterministic performance goal of providing a leak-tight barrier for approximately 24 hours is intended to provide adequate time for fission product decay such that the potential safety impact is reduced if a controlled release is necessary to prevent containment failure caused by overpressure. An example of a controlled release is venting of Mark I and Mark II boiling water reactor containments to prevent long-term containment failure caused by overpressure.

DISCUSSION:

During a severe accident, a containment can fail to perform its function of containing radioactive material release to the environment in two ways. First, the containment structure itself can fail (i.e., a breach) as a result of challenging environmental conditions inside the containment. Second, a radioactive material release can bypass the containment structure and enter the environment as a result of containment isolation valves not closing. For the NuScale design, an example of a containment bypass scenario is failure of chemical and volume control system piping outside containment with coincident failure of its isolation valves and the reactor decay heat removal systems.

For severe accidents that do not involve containment bypass, NuScale performed a severe accident analysis in an effort to show that a damaged core would be retained within the reactor vessel due to water in the containment cooling the reactor vessel outer surface, thus preventing a breach of the reactor vessel. If the reactor vessel remains intact, the containment vessel will remain an effective fission product boundary. Furthermore, if the reactor vessel should fail, NuScale concluded that the containment would still remain intact. The NuScale FSAR acknowledges that phenomenological uncertainties remain that could affect this conclusion.[8] Examples of uncertainties impacting the NuScale analysis include: (a) the potential formation of a metal layer on top of core debris in the reactor vessel lower plenum that would focus a high heat flow on a small area of the reactor vessel lower head; (b) intermetallic reactions that generate heat and could cause a self-propagating attack on the reactor vessel lower head; and (c) the heat transfer modeling for the reactor vessel and containment. Furthermore, should the reactor vessel fail, the containment vessel also could fail due to similar phenomena. Therefore, these uncertainties prevent the staff from confirming that the CCFP or deterministic containment performance goals are met. However, NuScale has a significantly different containment design than other new reactors in that the bottom of the NuScale containment is a steel head submerged in a reactor pool, which would prevent releases of radioactive material from submerged portions of the containment from becoming airborne. Severe accident simulations predict that should the NuScale core overheat, core debris would fall into the reactor vessel lower head. If the accumulated core debris resulted in failure of the reactor vessel lower head, it could then fall into the containment lower head and lead to failure of the containment lower

[8] NuScale letter RAIO-0219-64684 to NRC dated February 26, 2019 (ADAMS Accession No. ML19057A618).

head. Due to this, core debris could fall onto the reactor pool floor. Radioactive material releases from the containment through the failed containment lower head and from core debris on the reactor pool floor would be scrubbed by the reactor pool water, which is 21 meters deep. As a result, NuScale's FSAR states that containment lower head failure would not lead to a large release.

The applicant's conclusion of no large release is supported by the applicant's severe accident analysis for postulated module drop events. This analysis includes a severe accident with the NuScale power module lying on the reactor pool floor and with the containment assumed to be breached as a result of the drop impact. The analysis shows that the scrubbing effect of the water in the reactor pool reduces the offsite radiological dose to only a small fraction of the large release criterion defined by NuScale in the application.[9] The analysis conservatively models the effect of reactor pool scrubbing on the radiological release to the environment.[10] In the longer term, the reactor pool would continue to provide an effective barrier against the uncontrolled release of fission products beyond the initial 24-hour period following the onset of damage by preventing the radioactive material from becoming airborne again.

To demonstrate that the Safety Goal Policy Statement's quantitative health objectives are met, new reactor design certification applicants define a "large release" in their applications consistent with SECY-13-0029.[11] NuScale defined a large release as one producing a radiological dose greater than 200 rem to an individual located at the site boundary for 96 hours. In its DCA, NuScale described why defining a large release in this manner is consistent with the quantitative health objective regarding a low risk of prompt individual fatality from reactor accidents.[12] 200 rem is the dose at which significant early injuries start to occur, therefore it can be used as a reference value in the context of an extremely low probability (i.e., less than one in one million years) of potential reactor accidents to evaluate whether the objectives in the Safety Goal Policy Statement are met. Using this definition of large release does not imply that it is an acceptable limit for an emergency dose to the public.

Other relevant severe accident phenomena included in 10 CFR 52.47(a)(23) and addressed in the NuScale FSAR are in-containment and reactor vessel steam explosion, hydrogen combustion, and high-pressure core melt ejection. For in-containment steam explosion, NuScale concluded that there would be insufficient radioactive material airborne in the containment to result in a large release, assuming that the postulated steam explosion caused containment failure. Also, there would be several meters of water in the containment that could provide scrubbing of the release. For a steam explosion in the reactor vessel, NuScale concluded that the energy released would be insufficient to cause containment failure. NuScale also concluded that hydrogen combustion would not occur early in the accident while radioactive material is airborne, because the design does not have oxygen in containment to support combustion due to its use of an evacuated containment. Finally, NuScale concluded

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9 NuScale Standard Plant Design Certification Application Part 2 Tier 2, Revision 2, Section 19.1.6.2, "Results from the Low Power and Shutdown Operations Probabilistic Risk Assessment," October 2018 (ADAMS Accession No. ML18310A342).

10 NuScale letter RAIO-0817-55372 to NRC dated August 10, 2017 (ADAMS Accession No. ML17222A683); NuScale letter RAIO-0618-60459 to NRC dated June 14, 2018 (ADAMS Accession No. ML18165A438).

11 SECY-13-0029, "History of the Use and Consideration of the Large Release Frequency Metric by the U.S. Nuclear Regulatory Commission," March 22, 2013 (ADAMS Accession No. ML13022A207).

12 "Prompt fatality risk" refers to individual deaths that occur shortly (usually within a few weeks or months) after exposure to large doses of radiation.

that high-pressure melt ejection would not occur because the reactor's geometry results in depressurization before core debris could challenge the reactor vessel lower head.

For previous new reactor design certification application reviews, the staff evaluated containment performance for severe accidents by evaluating the likelihood of a physical failure of the containment. Based on the unique features of the NuScale design and insights from staff analysis, the staff has developed an alternative approach to evaluate technical issues associated with NuScale's containment performance that maintains a safety focus and is consistent with current NRC policy. The staff intends to apply the following criteria in its review:

- The large release definition used by NuScale is consistent with the objectives of the Safety Goal Policy Statement.

- The core damage frequency and the large release frequency are less than the goals of 10^{-4} per year and 10^{-6} per year, respectively. Meeting this criterion ensures that the Safety Goal Policy Statement quantitative health objectives for public risk are met.

- The conditional probability of containment failure by steam explosion in the reactor vessel causing failure of the containment upper head plus the conditional containment bypass probability is less than 0.1. Meeting this criterion ensures that the CCFP performance goal of 0.1 is met.

- For core damage accidents for which demonstration of in-vessel retention is inconclusive (i.e., sequences that do not involve containment bypass or steam explosion in the reactor vessel that could potentially lead to containment failure), the radioactive material release to the environment is less than that of a large release as defined by NuScale.

Collectively, meeting these criteria ensures that defense-in-depth is provided for severe accident mitigation and in the staff's view provides reasonable assurance of adequate protection of public health and safety.

<u>CONCLUSION</u>:

Although the staff is unable to confirm that the NuScale design meets the Commission's containment performance goals provided in SECY-90-016, SECY-93-087, and the associated SRMs, the staff considers that NuScale's unique design features can provide sufficient defense-in-depth to effectively mitigate severe accidents. Therefore, in its ongoing review of NuScale's containment performance, the staff plans to apply an alternative to the containment performance goals by verifying that the NuScale design prevents a large radiological release to the environment using the above review criteria. Through this approach, the staff will ensure that the NuScale design achieves the goals of containment performance by an alternate means and that this approach provides reasonable assurance of adequate protection of public health and safety.

COORDINATION:

The Office of the General Counsel has reviewed this paper and has no legal objection.

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SUBJECT: CONTAINMENT PERFORMANCE GOALS FOR THE NUSCALE SMALL MODULAR REACTOR DESIGN DATED MAY 8, 2019

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