UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

August 14, 2018

MEMORANDUM TO: Samuel S. Lee, Chief
Licensing Branch 1
Division of Licensing, Siting, and
Environmental Analysis
Office of New Reactors

FROM: Marieliz Vera Amadiz, Project Manager ***/RA/***
Licensing Branch 1
Division of Licensing, Siting, and
Environmental Analysis
Office of New Reactors

SUBJECT: U.S. NUCLEAR REGULATORY COMMISSION STAFF REPORT OF REGULATORY AUDIT OF FAILURE MODES AND EFFECTS ANALYSIS AND OTHER SUPPORTING DOCUMENTS FOR EMERGENCY CORE COOLING SYSTEM VALVES IN THE NUSCALE POWER, LLC, DESIGN CERTIFICATION APPLICATION

On January 6, 2017, NuScale Power, LLC (NuScale) submitted a design certification (DC) application for a small modular reactor (SMR) to the U.S. Nuclear Regulatory Commission (NRC) (Agencywide Documents Access and Management System (ADAMS) Accession No. ML17013A229). In a letter dated March 23, 2017, the NRC accepted for docketing the DC application for the SMR design submitted by NuScale (ADAMS Accession No. ML17074A087).

The NRC staff conducted an initial audit of the design of the emergency core cooling system (ECCS) valves described in the NuScale DC application, Final Safety Analysis Report (FSAR), Section 6.3, "Emergency Core Cooling System." The NRC staff performed the initial audit from November 28, 2017 to January 17, 2018, in accordance with an audit plan (ADAMS Accession No. ML17325B037). On February 26, 2018, the NRC staff issued a report on the initial audit of the design of the NuScale ECCS valves (ADAMS Accession No. ML18052A079).

From March 6, 2018 to May 22, 2018, the NRC staff conducted an audit of the Failure Modes and Effects Analysis (FMEA) and other supporting documentation for the NuScale ECCS valves. The NRC staff performed this audit in accordance with an audit plan (ADAMS Accession No. ML18060A068). The NRC staff conducted the audit by the review of ECCS valve design documents available in the NuScale electronic reading room and telephone conferences with the applicant. In addition, the NRC staff performed an onsite review of design information for the NuScale ECCS valves, including proof-of-concept testing, at the Curtiss-Wright Target Rock facility in Farmingdale, NY. The staff discussed the design of the ECCS valves with NuScale and Target Rock personnel during the onsite audit.

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The audit was conducted in accordance with the NRC Office of New Reactors (NRO) Office Instruction, NRO-REG-108, "Regulatory Audits" (ADAMS Accession No. ML081910260).

The audit report, audit participant list, and follow-up item list are enclosed with this memorandum.

Docket No. 52-048

Enclosures:
1. Audit Report
2. List of Audit Participants
3. Follow-Up Items List

cc: NuScale DC ListServ

SUBJECT: U.S. NUCLEAR REGULATORY COMMISSION STAFF REPORT OF REGULATORY AUDIT OF FAILURE MODES AND EFFECTS ANALYSIS AND OTHER SUPPORTING DOCUMENTS FOR EMERGENCY CORE COOLING SYSTEM VALVES IN NUSCALE POWER, LLC, DESIGN CERTIFICATION APPLICATION
DATED: August 14, 2018

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U.S. NUCLEAR REGULATORY COMMISSION

NUSCALE POWER, LLC

SUMMARY REPORT OF REGULATORY AUDIT REGARDING FAILURE MODES AND EFFECTS ANALYSIS AND OTHER SUPPORTING DOCUMENTS FOR THE NUSCALE EMERGENCY CORE COOLING SYSTEM VALVES

INTRODUCTION AND BACKGROUND

In a letter dated March 23, 2017, the U.S. Nuclear Regulatory Commission (NRC) accepted for docketing the NuScale Power, LLC (NuScale) Standard Plant Design Certification (DC) Application for a small modular reactor (SMR) design (Reference 1).

The NuScale Final Safety Analysis Report (FSAR) Tier 2, Section 6.3, "Emergency Core Cooling System," describes the emergency core cooling system (ECCS) for the NuScale reactor. On June 2, 2017, the NRC staff prepared Request for Additional Information (RAI) 8820 to obtain information on the design of the ECCS valves to support the NRC review of the NuScale DC application. In its response to RAI 8820, dated August 1, 2017 (Reference 2), NuScale provided information on the design of the ECCS valves and the schedule for completing activities to support the design of those valves. The NRC staff determined that audits of the design documentation would be the most efficient method to complete the review of the ECCS valves for the NuScale reactor.

In this report, the NRC staff summarizes the results of the audit of the Failure Modes and Effects Analysis (FMEA) and other supporting documents for the design of the ECCS valves to be installed in the NuScale reactor. This report also identifies the remaining items to be resolved for the NRC review of the design of the ECCS valves.

REGULATORY AUDIT BASES

The audit basis was to determine that the design of the NuScale ECCS valves satisfies the regulatory requirements for demonstrating the safety features of the NuScale reactor. The audit basis also was to confirm that the ECCS valve design is consistent with the assumptions for the performance of those valves in the NuScale DC application.

Title 10 of the *Code of Federal Regulations* (10 CFR), Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants," Section 52.47, "Contents of Applications; Technical Information," states the following:

> *The application must contain a level of design information sufficient to enable the Commission to judge the applicant's proposed means of assuring that construction conforms to the design and to reach a final conclusion on all safety questions associated with the design before the certification is granted. The information submitted for a design certification must include performance requirements and design information sufficiently detailed to permit the preparation of acceptance and inspection requirements by the NRC, and*

procurement specifications and construction and installation specifications by an applicant. The Commission will require, before design certification, that information normally contained in certain procurement specifications and construction and installation specifications be completed and available for audit if the information is necessary for the Commission to make its safety determination.

Paragraph (c) in 10 CFR 52.47 specifies the following requirements for applications that differ from the light-water reactor designs that have been licensed to date:

> *(c) This paragraph applies, according to its provisions, to particular applications:*
>
> *(1) An application for certification of a nuclear power reactor design that is an evolutionary change from light-water reactor designs of plants that have been licensed and in commercial operation before April 18, 1989, must provide an essentially complete nuclear power plant design except for site-specific elements such as the service water intake structure and the ultimate heat sink;*
>
> *(2) An application for certification of a nuclear power reactor design that differs significantly from the light-water reactor designs described in paragraph (c)(1) of this section or uses simplified, inherent, passive, or other innovative means to accomplish its safety functions must provide an essentially complete nuclear power reactor design except for site-specific elements such as the service water intake structure and the ultimate heat sink, and must meet the requirements of 10 CFR 50.43(e); and*
>
> *(3) An application for certification of a modular nuclear power reactor design must describe and analyze the possible operating configurations of the reactor modules with common systems, interface requirements, and system interactions. The final safety analysis must also account for differences among the configurations, including any restrictions that will be necessary during the construction and startup of a given module to ensure the safe operation of any module already operating.*

Paragraph (e) in Section 43 of 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," (10 CFR 50.43) required by 10 CFR 52.47(c)(2) specifies the following requirements:

> *(e) Applications for a design certification, combined license, manufacturing license, or operating license that propose nuclear reactor designs which differ significantly from light-water reactor designs that were licensed before 1997, or use simplified, inherent, passive, or other innovative means to accomplish their safety functions, will be approved only if:*
>
> *(1) (i) The performance of each safety feature of the design has been demonstrated through either analysis, appropriate test programs, experience, or a combination thereof;*

(ii) Interdependent effects among the safety features of the design are acceptable, as demonstrated by analysis, appropriate test programs, experience, or a combination thereof; and

(iii) Sufficient data exist on the safety features of the design to assess the analytical tools used for safety analyses over a sufficient range of normal operating conditions, transient conditions, and specified accident sequences, including equilibrium core conditions; or

(2) There has been acceptable testing of a prototype plant over a sufficient range of normal operating conditions, transient conditions, and specified accident sequences, including equilibrium core conditions. If a prototype plant is used to comply with the testing requirements, then the NRC may impose additional requirements on siting, safety features, or operational conditions for the prototype plant to protect the public and the plant staff from the possible consequences of accidents during the testing period.

The NRC staff reviewed the available design documents for the ECCS valves described in the NuScale FSAR Tier 2:

- Section 3.9.6, “Functional Design, Qualification, and Inservice Testing Programs for Pumps, Valves, and Dynamic Restraints,” and

- Section 6.3, “Emergency Core Cooling System.”

The NRC staff conducted this audit in accordance with the guidance provided in the Office of New Reactors (NRO)-REG-108, “Regulatory Audits” (Reference 3).

NRC AUDIT TEAM

Thomas G. Scarbrough, Senior Mechanical Engineer, Audit Lead
John Budzynski, Reactor Systems Engineer
Clinton Ashley, Reactor Systems Engineer
Luis Betancourt, Electronics Engineer
Omid Tabatabai, Senior Project Manager

AUDIT PURPOSE

The purpose of the audit was to evaluate the detailed design of the ECCS valves in support of the NuScale Standard DC application. In particular, the NRC staff evaluated the design of the ECCS valves and their individual subcomponents to support their performance assumptions in the DC application. For example, the NRC staff reviewed the FMEA and other supporting information for the ECCS valves to confirm the design characteristics assumed in the DC application. The NRC staff also evaluated the follow-up items from an initial audit report issued on February 26, 2018 (Reference 4) regarding the design of the ECCS valves and their subcomponents.

Among the most significant remaining items from the initial audit for the demonstration of the safety features of the ECCS valves and their individual subcomponents consisting of the main

valve, inadvertent actuation block (IAB) valve, trip valve and reset valve to satisfy the NRC regulations identified in the plan for this audit were the following:

1. The capability of the main valve to open fully in a timely manner for design-basis conditions when required;

2. The capability of the main valve to not partially or fully open prematurely;

3. The capability of the IAB valve to close and seal the vent line in a timely manner at the initial opening of the trip valve to prevent the main valve from opening partially or fully until the differential pressure between the reactor pressure vessel (RPV) and containment vessel (CNV) has reduced sufficiently to the specified conditions;

4. The capability of the IAB valve to open in a timely manner when the differential pressure between the RPV and CNV has reduced sufficiently to the specified conditions to allow the main valve to open fully to initiate emergency core cooling within the time specified in accident analyses;

5. The capability of the trip valve and line size, orifices, fittings, and installed configuration to vent the trip line adequately in a timely manner to allow the differential pressure between the RPV and CNV to close and seal the IAB valve against the force of the IAB spring to prevent the main valve from opening partially or fully (with consideration of hot borated water flashing to steam and boron deposits) until the differential pressure between the RPV and CNV has reduced sufficiently to the specified conditions; and

6. The capability of the trip valve and line size, fittings, and installed configuration to vent the trip line adequately in a timely manner after the IAB valve has opened to vent the main valve control chamber (with consideration of hot borated water flashing to steam and boron deposits) to allow the main valve to fully open within its stroke-time requirements.

<u>AUDIT PREPARATION</u>

The NRC staff issued a detailed audit plan (Reference 5) that identified the information needed for this audit. The audit plan requested that documentation related to the design of the ECCS valves in the NuScale reactor be provided for review. NuScale made available specific design documents related to the ECCS valves in the NuScale electronic reading room (eRR) and stated that some documents were available at the Curtiss-Wright Target Rock facility in Farmingdale, New York.

<u>NUSCALE ECCS DESIGN</u>

NuScale FSAR Tier 2, Section 6.3, provides the following description of the ECCS for the NuScale reactor design:

> *The emergency core cooling system (ECCS) provides core cooling during and after anticipated operational occurrences (AOOs) and postulated accidents, including loss-of-coolant accidents (LOCAs). The ECCS is an important NuScale Power Plant safety system in its safety-related response to LOCAs and as a component of both the reactor coolant and containment vessel (CNV) pressure*

boundaries. In conjunction with the containment heat removal function of containment, the ECCS provides core decay heat removal in the event of a loss of coolant that exceeds makeup capability.

The ECCS consists of three reactor vent valves (RVVs) mounted on the upper head of the reactor pressure vessel (RPV), two reactor recirculation valves (RRVs) mounted on the side of the RPV, and associated actuators located on the upper CNV as shown in Figure 6.3-1. All five valves are closed during normal plant operation and open to actuate the system during applicable accident conditions. The RVVs vent steam from the RPV into the CNV, where the steam condenses and liquid condensate collects in the bottom of the containment. The RRVs allow the accumulated coolant to reenter the RPV for recirculation and cooling of the reactor core. Placement of the RRV penetrations on the side of the RPV is such that when the system is actuated, the coolant level in the RPV is maintained above the core and the fuel remains covered. The cooling function of the ECCS is entirely passive, with heat conducted through the CNV wall to the reactor pool.

After actuation, the ECCS is a passive system that does not include long lengths of piping or holding tanks. The system is made up of the valves described above, which allow recirculation of the reactor coolant between the RPV and the CNV. The valves are maintained in the closed position during normal plant operation and receive an actuation signal upon predetermined event conditions (initiated by low RPV level or high containment level) to depressurize the RPV and allow flow of reactor coolant between the CNV and the RPV.

Reactor coolant inventory released during a LOCA event is collected and retained within the CNV which precludes the requirement to provide the makeup capacity necessary to replace coolant inventory lost to the core cooling function. The ECCS does not provide replacement or addition of inventory from an external source and does not provide a reactivity control function.

Facility design relies on passive design provisions that ensure sufficient coolant inventory is retained in the module to maintain the core covered and cooled. Makeup (addition) of reactor coolant inventory is not necessary or relied upon to protect against breaks. Reactor coolant inventory released from the reactor vessel during an in-containment unisolatable LOCA is collected and maintained within the CNV. After the ECCS valves open, the collected RCS inventory is returned to the reactor vessel by natural circulation. This return path to the vessel ensures that the core remains covered. The coolant inventory maintained in the reactor coolant system (RCS), assuming minimum allowed pressurizer (PZR) level, is adequate to provide sufficient coolant level in the CNV during a postulated design basis LOCA and maintain the reactor core covered. This is further discussed in Section 6.2.2.

Based on the description in the NuScale FSAR and design documents, each ECCS valve consists of 4 distinct valve subcomponents connected by several feet of tubing that contains borated reactor coolant as follows:

1. The main valve of the RVV that opens to allow steam in the RPV to be released to the CNV (and the main valve of the RRV that opens to allow coolant in the CNV to enter the

RPV) by reactor pressure (and a small spring force) when the main valve control chamber is vented to the CNV;

2. The solenoid-operated trip valve located outside the CNV in the cooling pool that is normally closed and is de-energized to open to vent borated reactor coolant from the main valve control chamber to the CNV;

3. The solenoid-operated reset valve located outside the CNV in the cooling pool that is normally closed and is energized to open to pressurize the main valve control chamber with borated reactor coolant sufficient to initially close the main valve against its small spring force; and

4. The IAB valve which is normally open but promptly closes (by the differential pressure between the RPV and CNV against a large spring force when the trip valve initially opens) to prevent the main valve control chamber from being vented to the CNV (and to keep the main valve fully closed) until the differential pressure between the RPV and CNV is reduced sufficiently to allow the spring to open the IAB valve and vent the main valve control chamber to allow the main valve to open.

AUDIT SCOPE

The primary scope of this audit was the review of the FMEA and other design documents related to the ECCS valves (including the main valve, IAB valve, trip valve, and reset valve) to be used in the NuScale SMR to verify that the design of those valves is consistent with their performance assumed in the NuScale FSAR. In addition, the audit included review of design information for the ECCS valves made available by NuScale at the Target Rock facility. The audit also included the review of the actions taken by NuScale to address the results of the initial audit of the ECCS valve design documentation.

AUDIT PERFORMANCE

In late 2017 and early 2018, the NRC staff performed an initial audit of the NuScale ECCS valve design to determine whether 10 CFR 52.47(c)(2) and 10 CFR 50.43(e) have been satisfied, including the following activities:

1. Determine whether the ECCS design drawings and other design documents support the first-of-a-kind (FOAK) valve design as reasonable to perform the safety functions specified in the NuScale DC application.

2. Determine whether the ECCS valves (and the valve subcomponents) will perform their safety functions in a timely manner over their full range of operational conditions.

3. Determine whether the ECCS valves will not inadvertently open when the differential pressure between the RPV and CNV exceeds the specified conditions.

4. Determine whether the FMEA for the ECCS valve design addresses potential failure mechanisms to provide reasonable assurance that the valve design analysis and testing will demonstrate the capability and reliability of the ECCS valves.

5. Determine whether the IAB valve in the ECCS valve can be assumed to be a passive device with a reliability consistent with the Commission policy on passive components with respect to the single failure criterion.

6. Determine whether the ECCS valve will reliably fully open during operation of the main valve and pressure release from the main chamber through the IAB valve.

7. Determine whether the plans for valve design testing will demonstrate the capability and reliability of the ECCS valve to support the assumptions in the NuScale DC application.

8. Determine whether the qualification plans are sufficient to provide reasonable assurance that a holder of a combined license for the NuScale design will demonstrate the qualification of the ECCS valves to perform their safety functions over the full range of operational conditions up through design-basis conditions.

Based on the initial audit, the most significant remaining items for the demonstration of the safety features of the ECCS valves to satisfy the NRC regulations included the following:

1. The capability of the main valve to open fully in a timely manner for design-basis conditions when required;

2. The capability of the main valve to not partially or fully open prematurely;

3. The capability of the IAB valve to close and seal the vent line in a timely manner at the initial opening of the trip valve to prevent the main valve from opening partially or fully until the differential pressure between the RPV and CNV has reduced sufficiently to the specified conditions;

4. The capability of the IAB valve to open in a timely manner when the differential pressure between the RPV and CNV has reduced sufficiently to the specified conditions to allow the main valve to open fully to initiate emergency core cooling within the time specified in accident analyses;

5. The capability of the trip valve and line size, orifices, fittings, and installed configuration to vent the trip line adequately in a timely manner to allow the differential pressure between the RPV and CNV to close and seal the IAB valve against the force of the IAB spring to prevent the main valve from opening partially or fully (with consideration of hot borated water flashing to steam and boron deposits) until the differential pressure between the RPV and CNV has reduced sufficiently to the specified conditions; and

6. The capability of the trip valve and line size, fittings, and installed configuration to vent the trip line adequately in a timely manner after the IAB valve has opened to vent the main valve control chamber (with consideration of hot borated water flashing to steam and boron deposits) to allow the main valve to fully open within its stroke-time requirements.

As a follow-up to the initial audit, the NRC staff conducted an audit from March 6, 2018 to May 22, 2018, of the FMEA and supporting documents for the design of the NuScale ECCS valves. Following the review of the NuScale documents made available in the eRR, the NRC staff conducted an onsite audit review at the Target Rock facility in Farmingdale, NY, from May 14 - 18, 2018. During the onsite audit, the staff reviewed numerous reports, calculations, analyses, and drawings related to the ECCS valve design, and conducted discussions with NuScale and Target Rock personnel. Specific documents reviewed are listed later in this audit report. The onsite audit was conducted in conjunction with an NRC vendor inspection evaluating the design

and test control, and other quality assurance activities, by Target Rock for the NuScale ECCS valves.

As noted above, the NRC regulations in 10 CFR 52.47 specify that a DC application must contain a level of design information sufficient to enable the Commission to judge the applicant's proposed means of assuring that construction conforms to the design and to reach a final conclusion on all safety questions associated with the design before the certification is granted. Paragraph (c) in 10 CFR 52.47 states, in part, in item (2) that an application for certification of a nuclear power reactor design that uses simplified, inherent, passive, or other innovative means to accomplish its safety functions must provide an essentially complete nuclear power reactor design except for site-specific elements, and must meet the requirements of 10 CFR 50.43(e). Paragraph (e) in 10 CFR 50.43 requires, in part, that applications for a design certification, which use simplified, inherent, passive, or other innovative means to accomplish the safety functions, will be approved only if (i) the performance of each safety feature of the design has been demonstrated through either analysis, appropriate test programs, experience, or a combination thereof; (ii) interdependent effects among the safety features of the design are acceptable, as demonstrated by analysis, appropriate test programs, experience, or a combination thereof; and (iii) sufficient data exist on the safety features of the design to assess the analytical tools used for safety analyses over a sufficient range of normal operating conditions, transient conditions, and specified accident sequences, including equilibrium core conditions. At this time, NuScale does not have operating experience or test results for its first-of-a-kind ECCS valves to satisfy 10 CFR 52.47 and 10 CFR 50.43(e). During the NRC staff review of the design of the ECCS valves for the NuScale DC application, NuScale made available a report on proof-of-concept (POC) testing of the ECCS valve design performed by Target Rock. During this audit, the NRC staff reviewed the adequacy of the POC testing to satisfy 10 CFR 52.47 and 10 CFR 50.43(e) for the NuScale DC application.

NuScale Task Order Agreement 127527, Task Order 1, “Category I Valve Concept Study and Preliminary Design,” Revision 0, dated October 17, 2012, specified that the purpose of the statement of work (SOW) was to define requirements to perform a conceptual design and to prepare a preliminary design for the NuScale ECCS valves. NuScale Task Order Agreement 14Z506, Task Order 4, “Emergency Core Cooling System Valve Design SOW,” Revision 0, dated September 20, 2013, indicated that the scope of the SOW was to define the tasks for a design study to determine the preliminary design of the ECCS valves. The background section of the SOW noted that preventing the ECCS valve from opening at high reactor pressure conditions may be a desirable feature to preclude inadvertent RCS blowdown. The design assessment section of the SOW included consideration of dual or series trip valves as possible design options. NuScale Task Order Agreement 15Z501(11), Task Order 11, “ECCS Valve Proof of Concept Statement of Work,” Revision 0, dated February 10, 2015, specified that the objective of the POC testing was to provide reasonable assurance of the feasibility of the FOAK design to support the DC application submittal. During the onsite audit, Target Rock personnel indicated that the POC testing provided information on whether to proceed with a conceptual design of the ECCS valve with four valve subcomponents.

During this audit, the NRC staff reviewed the POC testing conducted by Target Rock in 2015 to help support the demonstration of the ECCS valve for the NuScale DC application. The POC testing is described in NuScale Report ER-B020-3817, “Proof of Concept Test Report for Emergency Core Cooling (ECC) System Valves,” which states that the scope of the testing was to provide reasonable assurance of the feasibility of the first-of-a-kind engineering (FOAKE) design. The POC test report indicates that the testing demonstrated the viability of the design and expected operation of the disconnected pilot concept and IAB feature. The POC test report

identifies key aspects to be addressed during the detailed design and testing such as the following: (a) sizing of the trip valve is critical for the trip valve to adequately vent the trip line to allow operation of the main valve and to allow the IAB valve to immediately seat to prevent premature opening of the main valve; (b) sizing of the trip line, fittings, and orifice is critical to adequately vent the trip line; (c) in that the proof-of-concept testing included only air and water tests, the effects of hot water, steam, and flashing will need to be assessed; and (d) the effect on valve performance from the differences between test facilities and the RPV will need to be assessed.

The POC test report identified differences between the configuration and conditions for the valves used in the POC testing and the ECCS valves. During the onsite audit, the NRC staff evaluated the POC testing that was performed with pressurized air and cold water conditions for application to the proposed ECCS valve design. In addition, the staff discussed the details of the POC test report including the scope, equipment, test conditions, and applicability to the NuScale reactor conditions with NuScale and Target Rock personnel. The staff toured the Target Rock assembly and testing facilities, including those used for the POC testing. Target Rock personnel provided the IAB valve used for the POC testing for NRC staff study of the valve internals. The staff found that the IAB valve used during the POC testing is the same size and similar design compared to the final IAB valve design. In addition, the staff evaluated the 2-inch globe valve and its internals used to represent the main valve during the POC testing. Target Rock personnel indicated that the POC-tested 2-inch globe valve disc, parts, and internal volume are similar to the final design of the main valve of the 2-inch RRV. As indicated in NuScale Task Order Agreement 18Z509 and 18E, Task Order 20, “Fabrication of ECCS Engineering Test Valves,” Revision 0, dated March 26, 2018, Target Rock is currently manufacturing the Engineering Test Valves (ETVs) for the RRV, RVV, IAB valve, and Trip/Reset Valve (Trip/Reset Valve, TRV) to be used in demonstrating the final ECCS valve design.

During this audit, the NRC staff found that the POC testing did not include all of the performance requirements and conditions for the RVVs and RRVs to be used in the NuScale reactor. For example, the POC test report indicates that the testing was conducted with air and water that did not match the high temperature and pressure, and borated water conditions of the NuScale RCS. In addition, the NRC vendor inspection performed during the onsite audit identified concerns regarding the validity and reliability of the POC test data. In particular, the calibration and traceability of the measurement and test equipment (M&TE) used for the POC testing need to be verified for use of the POC test data. Further, the POC test equipment was not procured as safety-related components with specific internal dimension control and verification. NuScale should confirm that the findings from the NRC vendor inspection of the Target Rock activities related to the ECCS valves are resolved. Based on its review, the staff does not consider the POC testing to be sufficient (at this time) to demonstrate the safety features of the ECCS valves for the actual valve design, configuration, and operating and design-basis conditions of the NuScale reactor. In the follow-up item list enclosed with this audit report, the staff indicates the remaining issues to be resolved for the use of the POC test data to support the demonstration of the performance of the ECCS valves as part of the NuScale DC application review.

During the onsite audit, Target Rock personnel presented calculations that predict the performance of the ECCS valves, including the operating requirements for the IAB valve. For example, Target Rock personnel provided for NRC staff review preliminary sizing calculations, force balance calculations, inflow/outflow analysis calculations, pressure-temperature rating and hydrostatic test pressure calculations, bolting calculations, and temperature coefficient of expansion calculations. These calculations could not be fully validated by the POC test data because the system performance for the POC testing did not match the actual reactor design.

For example, the initial information regarding borated water in the main valve control chamber and subsequent flashing needs to be addressed in the calculations. As indicated in the follow-up item list enclosed with this audit report, NuScale should verify that the Target Rock calculations and documentation are finalized as quality assurance products for the final design of the ECCS valves if they are to be used to support the DC application.

Regarding the potential for an ECCS valve to partially open, the NRC staff discussed with NuScale and Target Rock personnel the potential failure mode for the main valve to remain partially open if the IAB valve did not close in sufficient time to maintain the pressure in the main valve control chamber following the opening of the trip valve. In such case, the pressure in the main valve control chamber could be reduced to allow the main valve disc to partially open. NuScale and Target Rock personnel had not specifically analyzed this potential failure mode. During the onsite audit, Target Rock personnel performed preliminary calculations to evaluate this failure mode and predicted that the valve might return to the closed position or might move to the full open position depending on the specific plant conditions. NuScale and Target Rock personnel indicated their engineering judgement that the main valve could not remain in a partially open condition for an extended time period. The follow-up item list enclosed with this audit report indicates the technical aspects for NuScale to address in resolving the safety question regarding a partially open failure mode for an ECCS valve.

In response to RAI 8815 in its letter dated July 21, 2017 (Reference 6), NuScale indicated that the IAB valve in the ECCS valve system is assumed to be a passive component with respect to the single failure criterion. In its RAI response, NuScale references Commission Paper SECY-94-084 (dated March 28, 1994), “Policy and Technical Issues Associated with the Regulatory Treatment of Non-Safety Systems (RTNSS) in Passive Plant Designs,” in support of its assumption. In discussing the single failure criterion for check valves in new reactors with passive cooling systems, SECY-94-084 specified that a failure probability on the order of 1E-4 per year or less would be low enough for a check valve in a new reactor to be considered a passive component with respect to the single failure criterion. In its RAI response, NuScale applies this Commission guidance to the IAB valve in its reactor. In particular, the NuScale letter dated July 21, 2017, states the following:

> *NuScale performed an evaluation using Target Rock main steam safety relief valves (MSSRVs) in use at boiling water reactors as a surrogate for the IAB arming valve. The pilot assembly of the Target Rock MSSRV is of similar design to the IAB valve, is made by the same manufacturer, and operates on the same principle of differential pressure. The operating experience for these valves was reviewed to identify failure events involving the pilot that would be applicable to the IAB, and the results were used to estimate the failure probability for the IAB valve. This evaluation determined the IAB to have a mean failure-to-close probability of 3.5E-4 per demand. When combined with the frequency of initiating events determined in the PRA that would demand the IAB, the failure frequency for any of the five IAB valves to close is 1.2E-5 per module critical year. Therefore, the reliability of the IAB feature meets the SECY-94-084 criterion of having a failure frequency less than 1E-4 per year. Based on the above, the failure of the ECCS valve IAB function meets the deterministic and probabilistic criteria for a passive failure and should not be considered an active failure concurrent with other analyzed events.*

During the onsite audit, the NRC staff discussed with Target Rock and NuScale personnel the NuScale assumption that the IAB valve is a passive component in the NuScale safety analysis. NuScale personnel referenced the response to RAI 8815 during those discussions, but did not have specific information on the basis for the reliability value assumed for the IAB valve. The staff also noted that only a few tests of the IAB valve were performed as part of the POC testing. For example, the POC test report indicates that the IAB valve operational testing included five strokes with water and five strokes with air to demonstrate that the IAB valve would close upon a trip valve actuation at high pressure conditions. The staff indicated that the NuScale response to RAI 8815 would be discussed with other NRC staff members.

Following the onsite audit, applicable NRC staff, including the probabilistic risk assessment, reactor systems, and mechanical engineering branches, discussed the justification provided in the NuScale response to RAI 8815 for the IAB valve to be assumed to be a passive component with respect to the single failure criterion. For example, the staff does not consider the information provided in the RAI response sufficient to justify the reliability value calculated by NuScale for the IAB valve based on an MSSRV. In addition, the staff does not consider the POC tests of the IAB valve to be sufficient to support the reliability value assumed in the RAI response. Based on its review, the staff considers the RAI response to not provide an adequate justification for the treatment of the IAB valve as a passive component with respect to the single failure criterion. The staff considers the spring-loaded IAB valve to be an active component that cannot be treated as a passive component with respect to the single failure criterion without additional justification. The specific remaining items regarding the NuScale analysis in its response to RAI 8815 are provided in the follow-up list enclosed with this audit report. NuScale should describe the plans to justify its consideration of the IAB valve similar to a passive component with respect to the single failure criterion to support the DC application.

In light of the changes to the specified size of the RVV and RRV in Revision 1 to the NuScale FSAR, the NRC staff discussed the following valve performance aspects with NuScale and Target Rock personnel during the onsite audit:

1. What are the C_v flow coefficients and critical pressure ratio X_T based on the new RVV and RRV sizes? In response, NuScale stated that the allowable ranges of the C_v and X_T in the ECCS valve design specifications have remained the same with the new RVV and RRV sizes.

2. What is the minimum flow areas (e.g., seat, exit, entrance, or midpoint) for the RVV and RRV in light of their new sizes? In response, NuScale stated that the minimum flow areas are determined by the exit areas into the CNV for the RVV and RRV.

3. Is there a more specific range of valve parameters to focus the RVV and RRV designs? In response, NuScale stated that the full ranges of the valve parameters are acceptable without a more narrow range to center the valve designs. NuScale stated that the safety analysis should apply the worst case value for each parameter (which might be the high or low value of the range) during the evaluation of the specific accident scenario.

At the onsite audit close-out meeting on May 17, 2018, the NRC staff discussed the results of the onsite audit of the ECCS valve design with NuScale and Target Rock personnel. In particular, the staff emphasized the significant cooperation and technical assistance provided by NuScale and Target Rock personnel during the onsite audit. Following the vendor inspection exit meeting on May 18, 2018, the NRC staff provided a brief summary of the results of the onsite audit to NuScale and Target Rock management.

On May 22, 2018, the NRC staff conducted a telephone conference to conclude the audit of the FMEA and supporting documents for the NuScale ECCS valves in accordance with the ECCS valve audit plan. During the audit exit briefing, the staff indicated that this audit report would describe the results of the ECCS valve audit and identify those technical issues that require further evaluation for the ECCS valve design. During the exit briefing, NuScale requested that the audit report indicate those review aspects that have been resolved by this audit.

In an enclosure to this audit report, the NRC staff indicates the aspects of the review of the NuScale ECCS valve design that have been resolved and those aspects that remain to be resolved to support the DC application. The following is a summary of the remaining unresolved items described in the enclosure to this audit report to demonstrate the design performance of the ECCS valves for the NuScale DC application:

1. The Proof of Concept (POC) testing provided support for the initial conceptual design of ECCS valves, but is not sufficient (at this time) to demonstrate the design performance of the ECCS RVV and RRV valve systems for the NuScale reactor in accordance with 10 CFR 52.47(c) and 50.43(e). In addition to addressing the POC test report conclusions, NuScale should resolve the following items for application of the POC test results to support the design performance of the ECCS valves:

   a. Applicability of the POC test fluid conditions to the reactor fluid conditions for temperature, pressure, and borated water.

   b. Applicability of the POC test valve size and tubing length, routing, and volume to the final ECCS valve system design to support the assumptions for IAB valve performance and validate IAB valve calculations.

   c. Adequacy of the POC test results to support the passive component assumption for the IAB valve in the safety analysis.

   d. Reliability of the POC test data for traceability and calibration of the pressure transducers and main disc position linear variable differential transformer (LVDT) used in the POC testing.

   e. Applicability of the internal dimensions of the valves used in POC testing to the final RRV design.

   f. Applicability of the POC testing of a 2-inch valve (similar to the RRV) to the performance of the 5-inch RVV for reactor fluid conditions and applicable accident scenarios, including low temperature overpressure protection (LTOP).

2. NuScale should resolve the potential failure mode for the main valve disc to open only partially if the main valve control chamber loses sufficient pressure to initiate main disc opening upon initial opening of the trip valve at high RCS pressure as indicated in the enclosure to this audit report.

3. NuScale should resolve the issues regarding the justification for the passive component assumption for the IAB valve in the safety analysis as indicated in the enclosure to this audit report.

4. NuScale should resolve the remaining FMEA questions as indicated in the enclosure to this audit report.

5. NuScale should resolve the comments on NuScale and Target Rock reports as indicated in the enclosure to this audit report.

6. NuScale should resolve the remaining follow-up items from the initial ECCS valve audit as indicated in the enclosure to this audit report.

CONCLUSIONS

Based on this audit, the NRC staff concludes that, at this time, NuScale has not provided sufficient information necessary to demonstrate the safety features of the ECCS valves as required by 10 CFR 52.47(c)(2) and 10 CFR 50.43(e). In particular, NuScale has not demonstrated the capability and reliability of the ECCS valves to perform their safety functions to support the NuScale DC application. In an enclosure to this report, the NRC staff provides a detailed list of the remaining items to be addressed regarding the demonstration of the design of the ECCS valves. The staff will discuss the findings from this audit with NuScale to determine the most efficient method to address the follow-up items for the demonstration of the design of the NuScale ECCS valves to support the completion of the NRC review of the NuScale DC application.

DOCUMENTS REVIEWED

General

NuScale Final Safety Analysis Report, Tier 2, Section 6.3, "Emergency Core Cooling System," Revision 1.

NuScale Design Specification EQ-B020-2140, "ASME Design Specification for Emergency Core Cooling System Valves," Revision 3, dated February 14, 2018.

NuScale Task Order Agreement 127527, Task Order 1, "Category I Valve Concept Study and Preliminary Design," Revision 0, dated October 17, 2012.

NuScale Task Order Agreement 14Z506, Task Order 4, "Emergency Core Cooling System Valve Design SOW," Revision 0, dated September 20, 2013.

NuScale Task Order Agreement 15Z501(11), Task Order 11, "ECCS Valve Proof of Concept Statement of Work," Revision 0, dated February 10, 2015.

NuScale Task Order Agreement 15Z501(12), Task Order 12, "ECCS Phase 2 Review Statement of Work," Revision 0, dated October 2, 2015.

NuScale Task Order Agreement 16Z540, Task Order 13, "Primary Valve Seismic Update," Revision 0, dated February 9, 2016.

NuScale Task Order 17Z503, MSA CO-1012-2074, Task Order 16, "Emergency Core Cooling System Valve Detailed Design Statement of Work," Revision 2, dated March 2, 2017.

NuScale Task Order Agreement 18Z509 and 18E, Task Order 20, "Fabrication of ECCS Engineering Test Valves," Revision 0, dated March 26, 2018.

Plans and Analyses

NuScale Report ER-B020-6113, "ECCS Valve Subcomponent Level FMEA," Revision 0, dated January 26, 2018, forwarding Curtiss-Wright Target Rock Report No. 9969, "Subcomponent Level Failure Modes and Effects Analysis (FMEA) of the NuScale ECCS Valve System," Revision A, dated January 25, 2018.

NuScale Report ER-B020-6117, "ECCS Valve Qualification Plan," Revision 0, dated March 27, 2018, forwarding Curtiss-Wright Target Rock Report No. 9986, "Qualification Plan for NuScale Emergency Core Cooling System Valves," dated March 22, 2018.

Drawings

NuScale Drawing ED-B020-2617, "Reactor Vent Valve Drawing," Revision 1, dated March 29, 2018, forwarding Target Rock Drawing No. ECCS-RVV-001, "Reactor Vent Valve (RVV) Assembly, Pilot Operated, Fail Open, On/Off, NPS 5 Class 2500, Flanged," Revision 2, dated September 15, 2017.

NuScale Drawing ED-B020-2650, "Reactor Recirculation Valve Drawing," Revision 1, dated March 29, 2018, forwarding Target Rock Drawing No. ECCS-RRV-001, "Reactor Recirculation Valve (RRV) Assembly, Pilot Operated, Fail Open, On/Off, NPS 2 Class 2500, Flanged," Revision 2, dated September 15, 2017.

NuScale Drawing ED-B020-5679, "Inadvertent Actuation Block Drawing," Revision 1, dated March 29, 2018, forwarding Target Rock Drawing No. ECCS-IAV-001, "IAB Valve Assembly," Revision 2, dated September 15, 2017.

NuScale Drawing ED-B020-2651, "Trip and Reset Valves Drawing," Revision 1, dated March 29, 2018, forwarding Target Rock Drawing No. ECCS-TRV-001, "Trip/Reset Valve (TRV) Assembly, On/Off, NPS 3 Sch 160 BW Connection," Revision 2, dated September 15, 2017.

NuScale Drawing ED-B020-5690, "Single Trip Valve Drawing," Revision 1, dated March 29, 2018, forwarding Target Rock Drawing No. ECCS-TV-001, "Trip Valve (TV) Assembly, On/Off, NPS 3 Sch 160 BW Connection," Revision 2, dated September 15, 2017.

Reports

NuScale Report ER-B0202-3817, "Proof of Concept Test Report for Emergency Core Cooling (ECC) System Valves," Revision A, dated December 18, 2015, forwarding Curtiss-Wright Target Rock Report 9785, "Proof of Concept Test Report for Emergency Core Cooling (ECC) System Valves," dated December 14, 2015.

NuScale ER-B020-6052, "ECCS RVV Diffuser Report," Revision 0, dated March 5, 2018, forwarding Curtiss-Wright Target Rock Report No. 9967, "NuScale ECCS RVV Diffuser Report," Revision A, dated February 15, 2018.

NuScale Report ER-B020-6289, "ECCS Valve Description," Revision 0, dated March 27, 2018, forwarding Curtiss-Wright Target Rock Report No. 10013, "System Description and Summary

Report for Detail Design of the Emergency Core Cooling (ECC) System Valves," Revision A, dated March 9, 2018.

NuScale ER-B020-6230, "Preliminary ASME Design Report for RRV," Revision 0, dated march 29, 2018, forwarding Curtiss-Wright Target Rock Report No. 9994, "ASME Design Report for Target Rock Valve Model ECCS-RRV-001 Code Class 1," Revision 0, dated February 20, 2018.

NuScale ER-B020-6306, "Preliminary ASME Design Report for RVV," Revision 0, dated March 29, 2018, forwarding Curtiss-Wright Target Rock Report No. 10021, "ASME Design Report for Target Rock Valve Model ECCS-RVV-001 Code Class 1," Revision 0, dated March 9, 2018.

NuScale ER-B020-6307, "Preliminary ASME Design Report for Pilot Valves," Revision 0, dated March 29, 2018, forwarding Curtiss-Wright Target Rock Report No. 10018, "ASME Design Report for Target Rock Valve Models ECCS-TRV-001 and ECCS-TV-001 Code Class 1," Revision 0, dated February 26, 2018.

Calculations

Target Rock Calculation, "NuScale ECCS Inadvertent Actuation Block (IAB) Valve Force Balance Calculation for Valve Model ECCS-IAB-001," Revision 0, dated January 9, 2018.

Target Rock Calculation, "NuScale ECCS Reactor Recirculation Valve (RRV) Force Balance Calculation for Target Rock Valve Model ECCS-RRV-001," Revision 0, dated January 9, 2018.

Target Rock Calculation, "NuScale ECCS Reactor Vent Valve (RVV) Force Balance Calculation for Target Rock Valve Model ECCS-RVV-001," Revision 0, dated January 9, 2018.

Target Rock Calculation, "Temperature Coefficient of Expansion Calculations for ECCS-RRV-001," dated July 14, 2017, ECCS-RVV-001, dated June 14, 2017, ECCS-IAB-001, dated July 6, 2017; ECCS-TRV-001 and ECCS-TV-001, dated September 15, 2017.

Target Rock Calculation, "NuScale IAB Sizing Calculation," dated June 20, 2017.

Target Rock Calculation, "NuScale RRV Sizing Calculation," dated March 31, 2017.

Target Rock Calculation, "NuScale RVV Sizing Calculation," dated March 31, 2017.

Target Rock Calculation, "NuScale ECCS Main Valve Pressure-Temperature Rating and Hydrostatic Test Pressure Calculations," Revision 0, dated May 9, 2017.

Target Rock Calculation, "NuScale ECCS Actuators (Trip/Reset Valves) Pressure-Temperature Rating and Hydrostatic Test Pressure Calculations," Revision 0, dated May 9, 2017.

Target Rock Calculation, "NuScale ECCS Reactor Recirculation Valve (RRV) Bonnet Bolting Calculation for Target Rock Valve Model ECCS-RRV-001, Revision 0, dated October 31, 2017.

REFERENCES

1. NRC Letter, "NuScale Power, LLC. – Acceptance of an Application for Standard Design Certification of a Small Modular Reactor," dated March 23, 2017 (ADAMS Accession Number ML17074A087).

2. NuScale Power, LLC Response to NRC Request for Additional Information No. 47 (eRAI No. 8820) on the NuScale Design Certification Application, dated June 2, 2017 (ADAMS Accession No. ML17213A540).

3. NRO-REG-108, "Regulatory Audits", April 2, 2009 (ADAMS Accession No. ML081910260).

4. "Report of Initial Regulatory Audit for Emergency Core Cooling System Valves in NuScale Power, LLC, Design Certification Application," dated February 26, 2018 (ADAMS No. ML18052A079).

5. "Audit Plan for Regulatory Audit of Nuscale Power, LLC, Failure Modes and Effects Analysis and Other Design Information for Emergency Core Cooling System Valves," dated March 5, 2018 (ADAMS Accession No. ML18060A068).

6. NuScale Power, LLC Response to NRC Request for Additional Information No. 36 (eRAI No. 8815) on the NuScale Design Certification Application, dated July 21, 2017 (ADAMS Accession No. ML17202V093).

U.S. NUCLEAR REGULATORY COMMISSION

REGULATORY AUDIT REGARDING FAILURE MODES AND EFFECTS ANALYSIS AND OTHER SUPPORTING DOCUMENTS FOR THE EMERGENCY CORE COOLING SYSTEM VALVES IN THE NUSCALE POWER, LLC DESIGN CERTIFICATION APPLICATION

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U.S. NUCLEAR REGULATORY COMMISSION

REGULATORY AUDIT REGARDING FAILURE MODES AND EFFECTS ANALYSIS AND OTHER SUPPORTING DOCUMENTS FOR THE EMERGENCY CORE COOLING SYSTEM VALVES IN THE NUSCALE POWER, LLC DESIGN CERTIFICATION APPLICATION

Follow-Up Items from NRC Staff Audit of Failure Modes and Effects Analysis and Other Supporting Information for NuScale Emergency Core Cooling System Valves

The follow-up items from the NRC staff audit of the Failure Modes and Effects Analysis (FMEA) and other supporting information for the NuScale Emergency Core Cooling System (ECCS) valves described in the NuScale design certification (DC) application are provided below. In addition, the status of initial comments during the audit is indicated in the following list.

NuScale Report ER-B0202-3817, "Proof of Concept Test Report for Emergency Core Cooling (ECC) System Valves," Revision A, dated December 18, 2015

1. The proof-of-concept (POC) test report identifies key aspects to be addressed during the detailed design and testing such as the following: (a) sizing of the trip valve is critical for the trip valve to adequately vent the trip line to allow operation of the main valve and to allow the inadvertent actuation block (IAB) valve to immediately seat to prevent premature opening of the main valve; (b) sizing of the trip line, fittings, and orifice is critical to adequately vent the trip line; (c) in that the proof-of-concept testing included only air and water tests, the effects of hot water, steam, and flashing will need to be assessed; and (d) the effect on valve performance from the differences between test facilities and the reactor pressure vessel (RPV) will need to be assessed. NuScale should address these key aspects identified in the POC test report to demonstrate the safety features of the ECCS valves and their valve subcomponents.

2. NuScale should address the following items for application of the POC test results to the final design of the reactor vent valve (RVV) and reactor recirculation valve (RRV) for the ECCS valves:

   a. Applicability of the POC test fluid conditions to the reactor fluid conditions for temperature, pressure, and borated water.

   b. Applicability of the POC test valve size and tubing length, routing, and volume to the final ECCS valve system design to support the assumptions for IAB valve performance and validate IAB valve calculations.

   c. Adequacy of the POC test results to support the passive component assumption for the IAB valve in the safety analysis.

d. Reliability of the POC test data for traceability and calibration of the pressure transducers and main disc position linear variable differential transformer (LVDT) used in the POC testing.

e. Applicability of the internal dimensions of the valves used in POC testing to the final RRV design. For example, the following information for the POC test equipment should be compared to the final ECCS valve design: (1) main valve and IAB valve internal dimensions and clearances; (2) internal volumes (main valve control chamber, IAB valve above and below bellows, and tubing); (3) main valve and IAB valve spring sizes, constants, and preloads; (4) valve seat sizes (main valve, IAB valve, trip valve, and reset valve); (5) main valve orifice and filter; (6) main valve and trip valve elevation difference and tubing routing; and (7) line flow restrictions (e.g., adapters, fittings, and line internal dimensions).

f. Applicability of the POC testing of a 2-inch valve (similar to the RRV) to the performance of the 5-inch RVV for reactor fluid conditions and applicable accident scenarios, including low temperature overpressure protection (LTOP).

3. NuScale should describe its plans to resolve the safety questions regarding the design demonstration testing of the ECCS valves to support the DC application.

<u>Partial Open ECCS Valve Failure Mode</u>

1. NuScale should address the following technical aspects in resolving the safety questions regarding a partially open failure mode for an ECCS valve:

a. The main valve needs to be demonstrated to not be subject to tilting that could cause binding during valve actuation by the opening flow for the RVV and RRV, including diffuser turbulent flow for the RVV.

b. The pressure drop in the main valve control chamber upon operation of the IAB valve needs to be evaluated to demonstrate that the main valve will not open prematurely.

c. The preliminary calculations of the performance of the main valve upon partially opening need to be completed and verified with justification by analysis or testing as necessary, including demonstrating that the main valve will fully close or fully open in a timely manner in the event of a partial open condition.

d. The verification activities being performed by NuScale and Target Rock to demonstrate that a partial open failure mode of the ECCS valve is not credible need to be finalized as quality assurance products that are available for NRC staff review.

2. NuScale should describe its plans to resolve the safety questions regarding the potential partial open failure mode for the main valve of the ECCS valves to support the DC application.

<u>IAB Valve Passive Component Assumption</u>

1. NuScale should justify its assumption that the guidance in Commission Paper SECY-94-084 (dated March 28, 1994), “Policy and Technical Issues Associated with the Regulatory Treatment of Non-Safety Systems (RTNSS) in Passive Plant Designs,” for categorizing a check valve in a new reactor as a passive component with respect to the single failure criterion is applicable to

the spring-operated IAB valve in the NuScale reactor or identify alternative treatment for applying single failure to the IAB.

2. NuScale should address the following technical aspects in resolving the safety questions regarding its assumption that the IAB valve may be categorized as a passive component with respect to the single failure criterion or appropriately consider single failure for the IAB in the accident analysis:

a. The IAB valve has a different design from the pilot for the main steam safety relief valve (MSSRV), such that the MSSRV failure rate has not been demonstrated as applicable to the IAB valve without significant operating or testing experience.

b. The IAB valve has multiple operating positions of initially open, close, and re-open in performing its safety functions while the NuScale response to RAI 8815 only evaluates a failure to close in calculating the assumed failure rate for the IAB valve.

c. The low demand frequency assumed in the NuScale response to RAI 8815 to convert the failure rate of the IAB valve per demand to failure rate per year has not been justified in calculating the failure rate of the IAB valve to satisfy the Commission paper guidance for passive components.

3. NuScale should describe the plans to justify its consideration of the IAB valve similar to a passive component with respect to the single failure criterion to support the DC application.

NuScale Report ER-B020-6113 (Revision 0, dated January 26, 2018), "ECCS Valve Subcomponent Level FMEA"

General

1. An FMEA is performed to identify potential failure modes of a new component design and to enable the design process to avoid the significant failure modes of the component. An FMEA prioritizes the significance of the potential failure modes by calculating a Risk Priority Number (RPN) for each failure mode by the multiplication of assigned Severity, Occurrence and Detection rating numbers. Based on the FMEA results, the potential failure modes with the highest priority RPNs are specified for corrective action as part of the design process or other activities to address those significant failure modes. NuScale Report ER-B020-6113 (Revision 0, dated January 26, 2018), "ECCS Valve Subcomponent Level FMEA," forwards the FMEA of the NuScale ECCS valves performed by Target Rock. The FMEA for the NuScale ECCS valves indicates an RPN of 200 as the significance level for potential failure modes without justifying the RPN methodology.

Status: During the onsite audit, the NRC staff discussed with NuScale and Target Rock personnel the various approaches that could be applied in performing the FMEA for the NuScale ECCS valves. For example, some approaches assign the top 20% of the RPNs as failure modes that will be addressed for corrective action. The FMEA should specify the basis for the selection of 200 for the significant RPN level in light of many failure modes that approach the 200 level.

2. The FMEA report describing the categorization of potential failure modes of the ECCS valves and their four valve subcomponents identifies the IAB valve bellows assembly and the potential for debris to damage operational clearances as the most significant risk items in that their RPNs are calculated to be 200 or above. The FMEA report states that partial open failures were

considered for the ECCS main valve. The FMEA indicates that several components in the main valve body were postulated as a risk of causing a partial open failure if they are damaged or entrained with debris. Other components outside of the main valve (such as the IAB valve, hydraulic line, and trip valve) were said to have postulated failures that could cause inadvertent opening of the main valve. The FMEA report concludes that no credible component failures were identified that would cause inadvertent opening or failure of the main valve to a partial open state. The FMEA report also notes that boric acid crystallization is a phenomenon that might affect the function of the valve system. The FMEA does not include plans to address these failure modes as part of the design process.

Status: During the onsite audit, the NRC staff discussed the conclusions of the FMEA with NuScale and Target Rock personnel. NuScale should describe the plans to address the FMEA report conclusions to demonstrate the safety features of the ECCS valves and their valve subcomponents to support the DC application.

3. In addition to the failure modes indicated in the FMEA report conclusions, the FMEA report identifies several failure modes that approach the RPN significance level of 200 (such as in Table 6-7). Minor uncertainty adjustments to the assignment of Severity, Occurrence, and Detection rating numbers for several failure modes would cause the RPN for those failure modes to approach or exceed the RPN significance level. An FMEA is intended to identify the significant failure modes for corrective action as part of the design process or other activities to avoid those failure modes.

Status: During the onsite audit, the NRC staff discussed potential failure modes that approach the assigned 200 RPN significance level with NuScale and Target Rock personnel. NuScale should describe the plans to resolve the significant failure modes for the ECCS valves identified by the FMEA, including consideration of the uncertainties in the rating numbers, to support the DC application.

4. The FMEA should identify the applicable mitigating factors to support the assigned Severity, Occurrence, and Detection rating numbers used in calculating the RPN for each failure mode. Several failure modes in the FMEA tables do not specify mitigating factors. For example, failure mode 6-7-9 in Table 6-7 for IAB disc failure does not provide the mitigating factors for the assigned Severity, Occurrence, and Detection rating numbers. In addition, some tables specify general mitigating factors that are not appropriate to address the specific potential failure mode in the new ECCS valve design. For example, failure mode 6-2-1 lists the redundant main valves and passive low pressure opening of the main valve when the RPV pressure is within approximately 20 pounds per square inch differential (psid) of the containment vessel (CNV) pressure. Failure mode 6-2-2 specifies the high reliability passive design as the mitigating factor. In addition, failure mode 6-3-1 references qualification as a mitigating factor, which is not a design factor.

Status: During the onsite audit, the NRC staff discussed with NuScale and Target Rock personnel the absence of mitigating factors or the specification of general mitigating factors for many potential failure modes identified in the FMEA. The staff indicated that the FMEA tables should specify the mitigating factors to support the calculated RPNs for the design of the ECCS valves. Itemized notes could be used to identify the mitigating factors that apply to several failure modes.

5. Several failure modes, such as 6-1-8, 6-3-2, 6-6-28, 6-6-52, 6-6-53, 6-7-4, 6-7-10, 6-8-4a, 6-8-10, 6-8-14, 6-8-19, and 6-8-20, in the FMEA tables specify inservice or routine testing as part

of the mitigating factors for those failure modes. The basis for these mitigating factors is not clear in the FMEA.

Status: During the onsite audit, the NRC staff discussed with NuScale and Target Rock personnel the references in the FMEA to inservice or routine testing as mitigating factors for potential failure modes. Based on the FMEA results, NuScale should verify that the plans for preservice testing (PST) and inservice testing (IST) are applicable for the mitigation of the specified failure modes.

6. FMEA Table 5-1 (Severity), Table 5-2 (Occurrence), and Table 5-3 (Detection) assign rating numbers of 1 to 10 for potential failure modes. Comments on the specific tables are as follows:

<u>Table 5-1, Severity (S)</u>

a. Table 5-1 assigns a Severity rating number of 5 for inadvertent/spurious opening of the main valve.

Status: During the onsite audit discussions, NuScale personnel clarified that inadvertent opening of the main valve was considered a mid-range 5 severity because it does not directly challenge the reactor fuel. The NRC staff considered this clarification to be acceptable.

b. Table 5-1 assigns a Severity rating number of 5 for failure of the IAB function.

Status: During the onsite audit discussions, NuScale personnel indicated that the mid-range severity number of 5 was assigned because the IAB valve is normally open. NuScale personnel stated that a severity of 8 to 10 would be applied for the potential failure of the IAB valve to re-open. The FMEA should clarify this difference in severity ratings for the appropriate functions of the IAB valve.

c. Table 5-1 assigns a Severity rating number of 6 for slow opening (est > 10 s, to 60 s) of the main valve.

Status: During the onsite audit discussions, NuScale personnel clarified that slow opening of the main valve was not a severe event because of the slow progression of core uncovery. The NRC staff considered this clarification to be acceptable.

<u>Table 5-2, Occurrence (O)</u>

a. Table 5-2 assigns Occurrence levels (and their rating numbers) as Not Credible (1), Remote (2 or 3), Moderate (4, 5, or 6), High (7 or 8), and Very High (9 or 10). However, the examples do not differentiate between these multiple rating numbers.

Status: During the onsite audit discussions, Target Rock personnel indicated that engineering judgment was applied to distinguish between events in the same Occurrence level. The FMEA should specify the basis for the assignment of rating numbers for each Occurrence level in calculating the applicable RPN where Table 5-2 does not differentiate between the specific rating numbers.

b. Table 5-2 defines the Remote Occurrence level as failures that may have been reported in relevant developmental testing, but not in service, with examples of bolt breakage or broken wires.

Status: During the onsite audit discussions, Target Rock personnel clarified that the operating experience with solenoid valves was applied in assigning the Remote Occurrence level to specific potential failure modes. The NRC staff considered this clarification to be acceptable.

c. Table 5-2 does not discuss potential failures related to the loss of power to the trip and reset valves.

Status: During the onsite audit discussions, Target Rock personnel indicated that the FMEA did not address loss of power or tubing performance because these aspects of the ECCS valve design are within the specific NuScale technical areas. NuScale should supplement the FMEA as necessary to address potential failure modes in technical areas not addressed by Target Rock (such as loss of power and tubing performance).

Table 5-3, Detection (D)

a. Table 5-3 assigns Detection levels (and their rating numbers) as Monitored (1), Detectable (2 or 3), Potential (4, 5, or 6), Late (7 or 8), and None (9 or 10). However, the examples do not differentiate between these multiple rating numbers.

Status: The FMEA should specify the assignment of rating numbers for each Detection level in calculating the applicable RPN where Table 5-3 does not differentiate between the specific rating numbers.

b. Table 5-3 assigns Detection rating numbers of 4 through 8 based on inservice inspection (ISI), IST and/or PST. If ISI and IST are only conducted during refueling outages every 2 years, ISI and IST will only detect some performance aspects prior to failure. Similarly, PST is only conducted prior to placing the valve in service.

Status: During the onsite audit, the NRC staff discussed with NuScale and Target Rock personnel the need to link the FMEA results with planned IST and ISI activities. NuScale should justify the Detection rating numbers for the specific failure modes based on whether the planned ISI, IST, or PST will detect the failure mode prior to its occurrence.

7. NuScale indicated that some design aspects of the safety features of the ECCS valves are planned to be addressed during qualification testing by the combined license (COL) holder. These include, for example, (1) the impact of flashing of the reactor coolant in the four valve subcomponents of the ECCS valves, (2) the establishment of the proper shim at the factory to provide assurance that the IAB spring will close and then re-open at the proper differential pressure between the reactor coolant system and containment vessel, and (3) the impact of boric acid on the four valve subcomponents of the ECCS valves. Design proof-of-performance testing by a DC applicant and component qualification testing by a COL holder are two separate activities. Specifically, design testing required by 10 CFR 52.47(c)(2) and 50.43(e) involves testing sufficient to demonstrate that a new design feature, which in this case is a new valve design, can perform its safety functions. Such testing may include a repetitive series of tests of an initially proposed valve design with modifications made to the valve design based on multiple test results until the necessary performance has been successfully demonstrated. In contrast to

design testing, qualification testing involves testing to verify that the valves as procured for installation in the facility are capable of performing their specific safety functions as indicated in the Final Safety Analysis Report (FSAR). Qualification testing does not generate design information at the FSAR level of detail needed for design certification; rather, qualification testing is a special treatment activity under 10 CFR Part 50, Appendix B, Criterion III, “Design Control,” and the requirements of the ASME *Boiler and Pressure Vessel Code* (BPV Code), Section III, among other NRC requirements for the design, manufacture, and installation of certain systems and components in a particular nuclear power plant. Qualification testing is not intended to provide proof-of-performance for new safety features or develop a first-of-a-kind prototype valve. Valve failure during qualification testing would result in an extent-of-condition evaluation of the design control process to identify the root cause of the failure and appropriate corrective action to resolve the specific valve failure and the discrepancy in the design control process. Such failure would not normally indicate that the high-level valve design was inadequate (thus requiring modification of the certified design by rulemaking); rather, failure during qualification testing normally indicates that the particular valve, as procured in accordance with its design specification, did not perform as designed (e.g., the valve did not meet its design specification or included a latent manufacturing flaw).

Status: During the onsite audit, the NRC staff discussed with NuScale and Target Rock personnel the importance of determining those design aspects to be verified for the DC application and those performance aspects that can be addressed as part of qualification activities by the COL holder. NuScale should describe the plans to resolve the design aspects of the safety features of the ECCS valves to support the DC application.

<u>Potential Failure Modes and Reliability Not Addressed in FMEA</u>

1. The FMEA report does not include an evaluation of the timeliness of the IAB valve function to initially close against a large spring force to isolate the main valve control chamber and then open at the appropriate differential pressure between the RPV and CNV to provide for the proper operation of the main disc of each ECCS valve.

Status: During the onsite audit, the NRC staff discussed with NuScale and Target Rock personnel the importance of the IAB valve to close promptly to avoid inadvertent opening of the main valve disc at high reactor pressure, and then to re-open at the proper pressure conditions to allow the main valve control chamber to depressurize such that the main valve disc will open to allow natural circulation to begin for reactor core cooling. NuScale should describe the capability of the IAB valve to meet its operating requirements in support of the DC application, and testing that is available to demonstrate IAB valve performance.

2. The FMEA report does not include an evaluation of the sizing of the IAB valve seat, trip valve, and the connecting tubing to provide for the depressurization of the main valve control chamber in a timely manner.

Status: During the onsite audit, the NRC staff discussed with NuScale and Target Rock personnel the importance of the sizing of the IAB valve seat, trip valve, and the connecting tubing to provide for the depressurization of the main valve control chamber in a timely manner. Target Rock personnel provided spreadsheet calculations that support the proposed sizing of these components, with plans to verify the calculations using actual test data. NuScale should describe the plans to verify the calculations for the sizing of the IAB valve seat, trip valve, and the connecting tubing to support the safety features of the ECCS for the DC application.

3. The FMEA report does not include an evaluation of the potential for boric acid precipitation and crystallization, as well as flashing of reactor coolant, to impact the performance of the ECCS valve and its subcomponents, with consideration of the small clearances of the tubing and valve seats.

Status: During the onsite audit, the NRC staff discussed with NuScale and Target Rock personnel the potential for boric acid precipitation and crystallization, as well as flashing of the reactor coolant, to impact the performance of the ECCS valve and its subcomponents. Target Rock personnel did not consider the boric acid to have an adverse effect on the clearances based on experience with other valves under high temperature conditions. NuScale personnel stated that the potential impact of the low temperature conditions in the containment pool is being considered. NuScale should describe the plans to demonstrate that boric acid precipitation and crystallization and flashing of reactor coolant will not impact the safety features of the ECCS valve to support the DC application.

4. The FMEA report does not address the potential failure mode related to borated liquid reactor coolant in the control chamber of the main valve and its effect on the operation and position of the main valve disc upon opening of the trip valve when a pressure drop occurs in the main valve control chamber prior to the IAB valve closing.

Status: During the onsite audit, the NRC staff discussed with NuScale and Target Rock personnel the potential failure mode related to borated liquid reactor coolant in the control chamber of the main valve and its effect on the operation and position of the main valve disc upon opening of the trip valve when a pressure drop occurs in the main valve control chamber prior to the IAB valve closing. Target Rock personnel prepared preliminary calculations that predicted that the main valve might fully open or might re-close following a partial opening depending on the specific reactor conditions. NuScale and Target Rock personnel do not believe that the main valve disc could stabilize in a partial open condition. NuScale should describe the plans to demonstrate the performance of the main valve disc as a result of the pressure drop in the main valve control chamber upon initial opening of the trip valve to support the DC application.

5. The FMEA report does not include an evaluation of the performance of the main disc with a small orifice and filter between the liquid borated reactor coolant in the main valve control chamber and steam in the pressurizer to transmit pressure of the borated reactor coolant for the intended valve performance.

Status: During the onsite audit, the NRC staff discussed with NuScale and Target Rock personnel the performance of the main disc with a small orifice and filter between the liquid borated reactor coolant in the main valve control chamber and steam in the pressurizer to transmit pressure of the borated reactor coolant for the intended valve performance. Target Rock personnel indicated that the orifice sizing will be based on analytical and historical experience with valves (such as safety relief valves). NuScale should describe the plans to demonstrate the performance of the main disc with the proper sizing of the orifice and filter for the safety features of the ECCS valve to support the DC application.

6. The FMEA report does not address the potential impact of the reverse flow from the diffuser upon actuation of the RVV.

Status: As indicated in the comments on the RVV Diffuser report, NuScale should describe its plans to demonstrate the performance of the RVVs in response to the reaction flow from the diffuser to support the DC application.

7. The FMEA report does not address the recirculation flow requirement of the RRVs to perform their safety function to allow condensed reactor coolant to enter the RPV from the CNV with sufficient flow to cool the reactor core in a timely manner.

Status: As indicated in the comments on the ECCS Qualification Plan, NuScale should describe the plans to demonstrate the safety feature of the RRVs to provide recirculation flow for core cooling to support the DC application.

8. The FMEA report addresses a potential tubing break, but does not discuss other potential failure modes of the tubing, such as binding or crimping.

Status: During the onsite audit, the NRC staff discussed with NuScale and Target Rock personnel the potential failure modes related to binding or crimping of the tubing. This issue was identified as a NuScale evaluation item. NuScale should describe its plans to demonstrate the design of the ECCS valves to avoid adverse effects of binding or crimping of the valve tubing to support the DC application.

9. NuScale assumes that the ECCS valve is a passive component with respect to the single failure criterion for such design aspects as IAB valve performance and partial opening of the main valve disc. Commission Paper SECY-94-084 indicated that check valves in new reactors with passive cooling systems might not be justified as passive components, because the driving head to open check valves in passive cooling systems might rely on gravity rather than pump flow. SECY-94-084 specified that a failure probability on the order of 1E-4 per year or less would be low enough to be considered a passive failure. The FMEA report does not address the reliability of the ECCS valve with respect to the passive component assumption.

Status: During the onsite audit, the NRC staff discussed with Target Rock and NuScale personnel the need to justify the assumption that the IAB valve is a passive component in the NuScale safety analysis. Following the onsite audit, the staff conducted additional internal discussions. The staff position on the NuScale assumption for the IAB valve as a passive component is addressed in this audit report.

<u>Table 6-1, Functional FMEA, Trip/Reset Valves</u>

The comments on Table 6-1 have been incorporated into other comments provided in this audit report. A few specific comments are provided below:

1. Failure mode 6-1-1 relates to the potential spurious opening of the trip valve that would cause the main valve to open. The Occurrence rating number for this failure mode is specified as 2, which is indicated as remote in Table 5-2.

Status: During the onsite audit, the NRC staff discussed with NuScale and Target Rock personnel the potential spurious opening of the trip valve. Target Rock personnel considered that the potential spurious opening of the trip valve from mechanical causes is remote based on operational experience with solenoid valves. Target Rock personnel indicated that electrical aspects were not addressed in the FMEA as outside the Target Rock scope. NuScale should

justify the basis for the remote failure assumption for the trip valves. The applicable NRC staff are evaluating the NuScale assumption for the reliability of the trip valve circuitry.

2. Failure mode 6-1-2 relates to leakage of the trip valve that might cause the main valve to open. The mitigating factors refer to control room leak detection. NuScale indicated that the leakage detection referenced for this failure mode applies to general RPV leakage rather than specific trip valve leakage. NuScale indicated that procedures will provide for plant shutdown in response to significant RPV leakage.

Status: The NRC staff will review the NuScale Technical Specification 3.4.5 for reactor operational leakage for consistency with the NuScale ECCS valve final design.

3. Failure mode 6-1-4 relates to the potential failure of the trip valve to open. The mitigating factors are specified as redundant RVVs and RRVs, and opening of the main valve by spring force when the pressure differential between the RPV and CNV reaches a small differential pressure.

Status: During the onsite audit, the NRC staff discussed with NuScale and Target Rock personnel the design of the main valve to open with low differential pressure when the IAB valve blocks depressurization of the main valve control chamber. NuScale should describe its reliance on the main valve spring to support the safety function of the ECCS valves.

4. Failure mode 6-1-7 relates to the potential rupture of the manifold providing the CNV boundary. The mitigating factors refer to hydrotesting in accordance with ASME Standard B16.34, "Valves – Flanged, Welded, and Welding End."

Status: During the NuScale audit at the Target Rock facility, Target Rock personnel indicated that the ASME BPV Code requirements for the ECCS valve will be satisfied, including the reference to ASME B16.34. This clarification is acceptable for this audit.

5. Failure mode 6-1-8 relates to the failure of the gasket providing the CNV boundary. The FMEA states that there is no effect on the main valve.

Status: The NRC staff is reviewing the design aspect of the ECCS valve with respect to the gasket providing the CNV boundary as part of RAI 9315, Question 03.08.02-14.

Table 6-2, Functional FMEA, IAB Valve

The comments on Table 6-2 have been incorporated into other comments provided in this audit report.

Table 6-3, Functional FMEA, Main Valves

The comments on Table 6-3 have been incorporated into the other comments provided in this audit report.

Table 6-4, Functional FMEA, Consideration of Partial Open Valve Failure

The comments on Table 6-4 have been incorporated into other comments provided in this audit report.

Table 6-5, Functional FMEA, Consideration of Valve Failure Caused by Boric Acid

The comments on Table 6-5 have been incorporated into other comments provided in this audit report. A few specific comments are provided below:

1. Table 6-5 lists potential failure modes caused by boric acid. NuScale should provide justification that the lessons learned from the Davis Besse RPV degradation, such as described in NRC NUREG/BR-0353 (Revision 1), "Davis-Besse Reactor Pressure Vessel Head Degradation," or documents prepared by the Institute of Nuclear Power Operations (INPO), have been addressed in the design of the ECCS valves, such as related to materials in failure mode 6-5-1.

Status: During the onsite audit, NuScale personnel indicated that the lessons learned related to boric acid effects from the Davis Besse event have been considered in its design of the ECCS valves. NuScale should include its consideration of the Davis Besse lessons learned as part of its final design documentation.

2. Failure mode 6-5-13 relates to the main valve filter being blocked by boric acid precipitation and crystallization. The FMEA categorizes this potential failure mode as remote.

Status: During the onsite audit, the NRC staff discussed with NuScale and Target Rock personnel the potential for the main valve filter to be blocked by debris. Target Rock personnel considered that such blockage would not have a significant effect on the capability of the main valve to open. NuScale should demonstrate that the blocking of the main valve filter is not credible for the ECCS valve to support the DC application.

Table 6-6, Component FMEA, Actuator Valves (TRV and TV)

The comments on Table 6-6 have been incorporated into other comments provided in this audit report.

Table 6-7, Component FMEA, IAB Valve

The comments on Table 6-7 have been incorporated into other comments provided in this audit report. A few specific comments are provided below:

1. Failure modes 6-7-5, 6-7-6, 6-7-7, and 6-7-8 relate to potential failures of the IAB valve involving the bellows assembly, bellows retainer, bellows, and rod, respectively. NuScale indicated that these high RPN significance failure modes would be mitigated by the availability of pressure under the rod that will operate the IAB valve.

Status: During the onsite audit, the NRC staff discussed with NuScale and Target Rock personnel the potential failure modes of the IAB valve involving the bellows assembly, bellows retainer, bellows, and rod. NuScale should demonstrate that the ECCS valve will perform its safety function in consideration of these failure modes to support the DC application.

2. Failure mode 6-7-9 relates to the potential jamming of the IAB disc from wear or entrapped debris causing inadequate operation of the IAB valve and main valve. The FMEA does not specify the mitigating factors for this high RPN significant failure mode.

Status: During the onsite audit, the NRC staff discussed with NuScale and Target Rock personnel the potential jamming for the IAB valve disc. NuScale should demonstrate the performance of the IAB valve disc to support the DC application.

3. Failure mode 6-7-11 relates to the leakage of the IAB O-ring causing increased time to vent control pressure and actuate the main valve. The FMEA does not specify mitigating factors for this high RPN significant failure mode.

Status: During the onsite audit, the NRC staff discussed with NuScale and Target Rock personnel the performance of the IAB valve O-ring. NuScale should justify the performance of the IAB valve with respect to O-ring performance to support the DC application.

4. Failure mode 6-7-19 relates to inadequacy of the shim washer that is used to adjust the set pressure of the IAB valve. The Severity, Occurrence, and Detection rating numbers are specified as 1 for this failure mode.

Status: During the onsite audit, the NRC staff discussed with NuScale and Target Rock personnel the shim to be provided in the IAB valve. The shim is installed in the factory at nominal conditions to provide the proper set pressure for the IAB valve when operating in the reactor environment. Target Rock personnel indicated that the proper lift for hot conditions would be verified. NuScale should demonstrate that the shim installed in the factory will be appropriate in the reactor environment, such as the temperature differential, to support the DC application.

Table 6-8, Component FMEA, Main Valves

The comments on Table 6-8 have been incorporated into other comments provided in this audit report. A few specific comments are provided below:

1. Failure mode 6-8-5 relates to the potential jamming from wear or entrapped debris of the sleeve that allows axial movement of the main disc. The mitigating factor specifies a proven design with controlled clearances for operability under design conditions.

Status: During the onsite audit, the NRC staff discussed the potential jamming of the main valve with NuScale and Target Rock personnel. NuScale personnel stated that this mitigating factor relates to the Target Rock valve design and its analysis of appropriate clearances under various operating conditions. NuScale should demonstrate the capability of the main valve to open fully without jamming as part of the resolution of the partial open failure mode.

2. Failure mode 6-8-17 relates to the potential clogging of the filter assembly with debris that could cause inadvertent main valve opening. The FMEA specifies this failure mode as low significance.

Status: During the onsite audit, the NRC staff discussed the potential clogging of the filter assembly with NuScale and Target Rock personnel. NuScale should demonstrate the performance of the control orifice and filter for the safety function of the ECCS valves to support the DC application.

3. Failure mode 6-8-46 relates to the impact of the diffuser installed at the outlet of the RVVs. The FMEA assigns Severity, Occurrence, and Detection rating numbers of 1 for this failure mode.

Status: During the onsite audit, the NRC staff discussed the RVV diffuser with NuScale and Target Rock personnel. NuScale should verify that the evaluation of this failure mode and its rating is consistent with the resolution of the comments on the RVV diffuser report in this audit report.

NuScale Report ER-B020-6289, "ECCS Valve Description"

1. Section 3.4 states that the diffuser for the RVV contains small holes to limit the outlet flow velocity and force of the flow stream on components in the vicinity of the RVV outlet. What are the plans to address the impact on the interior of the RVV and main valve control chamber?

Status: During the onsite audit, NuScale and Target Rock personnel described the determination of the reaction load on the RVV caused by the flow through the holes in the diffuser. The specific comments on the RVV diffuser are provided later in this audit report.

2. Section 3.7 describes the self-opening actuator feature at low pressure, such that the main valve return spring will open the valve without the need for trip valve de-energization. Does this also apply if the RPV is at high pressure and the differential pressure with the CNV is very small?

Status: During the onsite audit discussions, NuScale personnel stated that differential pressure is the correct parameter for the self-opening actuator feature. NuScale plans to correct this reference to reactor pressure in the ECCS Valve Description report.

3. Section 3.7.1 states that the main disc feed orifice filter has a large area to mitigate debris. What are the plans to demonstrate that the filter design is adequate?

Status: During the onsite audit discussions, NuScale personnel stated that the orifice filter for the main valve will be sized based on Target Rock experience with filters in nuclear service. NuScale personnel considered the RCS to be sufficiently pure to avoid filter problems. With respect to boron precipitation, NuScale personnel stated that the filter will be above the melting temperature of boron (approximately 330 °F) such that boron will not block the filter. NuScale personnel discussed the plan to flush the main valve orifice filter with the chemical volume and control system (CVCS) prior to plant startup with reliance on the purity of the CVCS fluid to avoid filter problems. Based on the onsite audit discussions, NuScale should document its justification for the performance of the main valve orifice filter to support the NuScale DC application.

4. Section 3.7.1 discusses the connecting tubing. What are the volumes of the connecting tubing for the RVV and RRV?

Status: During the onsite audit discussions, NuScale personnel provided the volumes of the RVV tubing and RRV tubing. NuScale personnel indicated that the water volume is important to confirm the proper opening time for the applicable ECCS valve. The staff discusses the remaining issues regarding the applicability of the water volume for the POC testing in this audit report.

5. Figure 4, Main Valve Cross-Section, includes an adjusting nut. What is the purpose of this nut and when can it be adjusted?

Status: During the onsite audit discussions, NuScale personnel clarified that the adjusting nut in the main valve drawing is used for manufacturing adjustments rather than installed adjustments. The NRC staff considers this clarification of the function of the adjusting nut to be acceptable for this audit.

6. Section 3.10 states that when the trip valve is activated, a small amount of control pressure will be vented before the IAB valve closes. What are the plans to demonstrate that the IAB will

close promptly to prevent the main valve control chamber from losing sufficient pressure to allow the main valve to partially or full open?

Status: The remaining issues regarding the demonstration that the IAB valve will close promptly to prevent the main valve control chamber from losing sufficient pressure to allow the main valve to partially or fully open are discussed in this audit report.

7. Section 3.10 states that upon initial trip valve opening, the slight loss of control pressure will recover and will equalize with reactor pressure. If the main valve control chamber loses sufficient pressure to allow partial opening of the valve, will the control pressure recover and reclose the valve?

Status: The remaining issues regarding the performance of the main valve if the control chamber loses sufficient pressure to allow partial opening of the valve are discussed in this audit report.

8. Section 3.10 states that the IAB valve setpoint is adjusted by bellows rod adjustment in the IAB disc and by shimming the spring. How and when can these adjustments be made?

Status: During the onsite audit discussions, NuScale personnel stated that these adjustments can only be made during the manufacturing process. NuScale should confirm that the ECCS valve design can accommodate appropriate adjustments during the manufacturing process for applicability to the reactor conditions.

9. Section 4.1.1 indicates the RVV and RRV nozzle opening diameters. How do these dimensions compare to the detailed drawings for the RVV and RRV?

Status: During the onsite audit discussions, NuScale personnel clarified that the minimum flow areas for the RVV and RRV are indicated in the latest design diagrams. The NRC staff considers this clarification to be acceptable for this audit.

10. Section 4.2.2 states that the TRV, TV, and main valve tubing is NuScale equipment. What are NuScale's plans to demonstrate the performance of this tubing?

Status: During the onsite audit discussions, NuScale personnel stated that the ECCS valve tubing will be 304 Stainless Steel seamless piping of Class 1 category similar to reactor sample lines. NuScale personnel stated that tubing supports will be addressed later during the design process. NuScale should demonstrate the performance of the connecting tubing and supports for the ECCS valves to support the DC application.

11. Section 4.2.3 indicates that provisions for detection of coolant leakage from the TRV and TV bonnet gaskets will be provided. What are these provisions?

Status: During the onsite audit discussions, NuScale personnel stated that the detection of leakage from the TRV and TV bonnet gaskets will be performed upon assembly. NuScale personnel also noted that Appendix J testing will be performed every refueling outage. NuScale should complete its justification for leakage detection to satisfy the applicable NRC staff review for the DC application.

12. Section 4.4 indicates that the main valve has two open switches and 2 closed switches for position indication. Do these switches indicate partial main valve positions, or only fully open and closed?

Status: During the onsite audit discussions, NuScale personnel stated that the position indication switches only indicate full open or full closed positions of the main valve. The NRC staff considers this clarification to be acceptable for this audit.

13. Section 4.4 discusses the prototype development for the main valve position switch that needed design changes based on performance degradation from high temperature conditions. What is the status of the development of the prototype position switch?

Status: During the onsite audit discussions, NuScale personnel stated that an upgrade to the main valve position switch is being designed for high temperature applications. NuScale plans to test the upgraded main valve position switch when available. NuScale should make available the results of the testing of the main valve position switch when completed.

14. The pdf files attached to Appendix B of the ECCS Valve Description Report do not open for viewing.

Status: During the audit close-out discussion on May 22, 2018, NuScale notified the NRC staff that the electronic reading room (eRR) does not allow for opening of the pdf files attached to Appendix B of the ECCS Valve Description report. The NRC staff does not consider these pdf files to be essential for the DC application review.

<u>NuScale ERR-B020-6052, ECCS RVV Diffuser Report</u>

1. In Section 4.1, Target Rock recommends that the design specification be changed to make the diffuser a separate item so as to not be installed during the pressure test. What are NuScale plans regarding the RVV diffuser as a separate item for testing?

Status: During the onsite audit discussions, NuScale personnel stated that Revision 3 to the ECCS Valve Design Specification will address the evaluation of the RVV diffuser as a separate item for testing. The NRC staff will confirm this provision for the RVV diffuser during the review of the ECCS Valve Design Specification as part of the follow-up audit of the NuScale design specifications.

2. In Section 4.3, Target Rock indicates that there is a significant change in density between the main valve section and outlet section resulting in sonic velocity at the outlet with choked flow and higher pressure drop through the diffuser. What are NuScale plans to address this performance attribute?

Status: During the onsite audit discussions, NuScale personnel stated that this performance attribute will be demonstrated by analysis with testing if necessary. NuScale should make this demonstration available for NRC staff review.

3. Section 4.3 indicates that a nonsafety-related computational fluid dynamics (CFD) analysis was applied to cross-check the hand calculations. How was the CFD analysis verified to be acceptable?

Status: During the onsite audit discussions, Target Rock personnel indicated that the nonsafety-related CFD analysis was applied only for information purposes. This issue was identified during the NRC vendor inspection conducted at the same time as the onsite audit. NuScale should address any appropriate actions based on the Target Rock response to the NRC vendor inspection findings.

4. Table 3 indicates that the spherical end of the diffuser will pass a certain percentage of the total mass flow through its flow area while the straight section of the diffuser will pass a different percentage of the total mass flow through its flow area. How will this estimation be verified?

Status: During the onsite audit discussions, Target Rock personnel indicated that the estimation of mass flow through the spherical end of the diffuser was obtained from the CFD analysis. This issue was identified during the NRC vendor inspection conducted at the same time as the onsite audit. NuScale should address any appropriate actions based on the Target Rock response to the NRC vendor inspection findings.

5. Table 4 and Appendix C provide the CFD results for low pressure conditions. Were high pressure conditions evaluated?

Status: During the onsite audit discussions, Target Rock personnel clarified that the CFD analysis was not performed for high pressure conditions. The NRC staff considers this clarification to be acceptable for this audit.

6. Section 4.4 specifies that the reaction force calculation is based on ASME BPV Code, Appendix O, "Rules for Design of Safety Valve Installations." Paragraph O-1230, "Other Mechanical Loads," specifies consideration of the transient impacting the valve mechanism. How has NuScale addressed this provision?

Status: During the onsite audit discussions, the NRC staff described the provisions in paragraph O-1230 of Appendix O to the ASME BPV Code. Target Rock personnel indicated that the potential effects on the valve mechanism from the reaction forces created by the turbulent flow in the RVV diffuser will be addressed as part of the final design. As a follow-up to this discussion, Target Rock personnel provided initial calculations predicting that the applied load from 2000 psid differential pressure on the main valve disc would not exceed the allowable stress at the orifice region. NuScale should demonstrate the design capability of the RVV valve mechanism when the valve design is complete.

7. Figure 5 indicates the orientation of the installation of the RVVs on the pressure vessel head. How is the torque moment during RVV discharge addressed?

Status: During the onsite audit discussions, Target Rock personnel stated that the torque moment during the RVV discharge will be addressed in the ASME Design Report. NuScale should confirm that this evaluation is included in the completed ASME Design Report.

8. Appendix B to the report describes the reaction load calculation. How will this reaction load calculation be verified?

Status: During the onsite audit discussions, Target Rock personnel stated that the design will include this reaction load plus an additional safety margin. NuScale should confirm that the final design for the ECCS valves includes the justification for the reaction load calculation for the RVV diffuser.

<u>NuScale ER-B020-6117 (Revision 0, dated March 27, 2018), "ECCS Valve Qualification Plan"</u>

1. Section 2.0 in the Qualification Plan specifies that the demonstration of ECCS valve functionality shall use analysis, testing, or a combination of both. ASME Standard QME-1-2007, "Qualification of Active Mechanical Equipment Used in Nuclear Power Plants," Subarticle QV-7100, "General Requirements," states that Section QV, "Functional Qualification Requirements for Active Valve Assemblies for Nuclear Power Plants," provides for qualification of a valve

assembly by a combination of testing and analysis. NuScale should ensure that Section QV provisions are met in the qualification of the ECCS valves.

Status: Based on discussions during the onsite audit, NuScale plans to update the Qualification Plan and also check the Design Specifications to verify that the language is consistent with ASME QME-1-2007.

2. Section 2.0 in the Qualification Plan when discussing ASME QME-1-2007, Subarticle QV-7300, "Specific Qualification Requirements for Valve Assemblies," states that the ECCS valves are QME Category B such that end load testing are not applicable. QME Category A valves are defined as valves that isolate a blowdown transient. ASME QME-1-2007 was prepared prior to the development of reactor designs that use valves to create a reactor blowdown to reduce RCS pressure to allow passive gravity cooling of the reactor core. Similar to squib valves in the AP1000 reactors, the qualification of the NuScale ECCS valves needs to address the blowdown loads to demonstrate their performance capability.

Status: Based on discussions during the onsite audit, NuScale plans to verify that the effects of the blowdown transient are addressed as part of the design of the ECCS valves.

3. Section 2.0 in the Qualification Plan when discussing ASME QME-1-2007, Subsubarticle QV-7410, "Initial Considerations," states that the ECCS valves are unidirectional. NuScale should address the qualification of the dual direction performance of the RRVs.

Status: During the onsite audit discussions, Target Rock personnel indicated that the unidirectional specification is intended to require a specific orientation for installation. Target Rock personnel stated that this language will be clarified in the Qualification Plan. The NRC staff finds this plan to be acceptable for this audit.

4. Section 2.0 in the Qualification Plan when discussing ASME QME-1-2007, Subsubarticle QV-7420, "Environmental and Aging," for the environmental and aging qualification of the pilot valves states that testing has been performed on a solenoid valve "essentially identical" to the trip and reset valves used in the NuScale ECCS valve. NuScale should provide additional direction for the justification that the environmental and aging qualification of the essentially identical solenoid valve is applicable to the trip and reset valves.

Status: During the onsite audit discussions, Target Rock personnel indicated that the Application Report for each ECCS valve will include the details to justify application of the environmental and aging qualification from similar valves. The NRC staff considers this response to clarify the intent of this provision in the Qualification Plan.

5. Section 2.0 in the Qualification Plan when discussing ASME QME-1-2007, Subsubarticle QV-7450, "Seismic Qualification," states that the main valve has no extended structure similar to self-actuated valve such that seismic testing is not required by QME-1. NuScale should provide additional justification to support the consideration that the main valve does not have an extended structure.

Status: Based on the onsite audit discussions, NuScale plans to include the justification for considering the main valve to not have an extended structure in the Application Report in accordance with ASME QME-1-2007. The NRC staff considers this plan to be acceptable for this audit.

6. Section 2.0 in the Qualification Plan when discussing Subsubarticle QV-7450 for the main valve states that a seismic test is not required. NuScale should ensure that the qualification plan addresses dynamic qualification of the ECCS valve in accordance with the provisions in ASME QME-1-2007, Paragraph QR-7312, “Dynamic loading.”

Status: Based on the onsite audit discussions, NuScale plans to clarify that dynamic loading as required by Paragraph QR-7312 in ASME QME-1-2007 for flow path and potential resonance response will be addressed as part of the Qualification Plan. The NRC staff considers this plan to be acceptable for this audit.

7. Section 2.0 in the Qualification Plan when discussing Subsubarticle QV-7450 for the pilot valves states that seismic qualification will be performed by a seismic test with a static load applied at the center of gravity of the extended operator structure as allowed per IEEE 344, “Recommended Practices for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations.” NuScale should ensure that the qualification plan provides assurance for the following: (a) the static load is applied along the least rigid axis, and (b) the static load is applied at the center of gravity of the extended structure. QME Case QME-007, “Alternative Methods for Seismic Qualification of Power-Actuated and Relief Valve Assemblies,” and ASME QME-1-2017, “Qualification of Active Mechanical Equipment Used in Nuclear Facilities,” provides additional guidance on the use of static side load testing for seismic qualification of valves.

Status: Based on the onsite audit discussions, NuScale plans to clarify the Qualification Plan for seismic qualification of the pilot valves using a static side load test. The NRC staff considers this plan to be acceptable for this audit.

8. Section 3.0 of the Qualification Plan in Sequence 3 specifies that the main valve and the IAB valve will each undergo 750 cycles separately. NuScale should address the performance of the main valve and IAB valve to satisfy the 1E-4 per year failure rate to support the passive component assumption with respect to the single failure criterion.

Status: During the onsite audit discussions, NuScale personnel referenced the responses to RAI 8815 for justification to consider the IAB valve as a passive component. This item is discussed in this audit report.

9. Section 3.0 of the Qualification Plan in Sequences 3, 4, and 7 indicates that seat lapping is allowed during the qualification process. NuScale should provide guidance that the seat lapping must not impact the capability of the main valve, IAB valve, or trip and reset valves to perform their safety functions to maintain an acceptable seat seal.

Status: Based on the onsite audit discussions, NuScale plans to provide additional guidance in the Qualification Plan regarding the acceptable frequency of seat lapping during the qualification testing. The NRC staff considers this plan to be acceptable for this audit.

10. Section 3.0 of the Qualification Plan in Sequence 8a, b, and c specifies high and low pressure performance of the main valve. NuScale indicated that the IAB valve will be disabled during these tests. NuScale should address the performance of the IAB valve during high and low pressure performance tests.

Status: During the onsite audit discussions, NuScale clarified that Sequence 8 of the Qualification Plan applies only to the flow capability of the main valve. The NRC staff considers this clarification to be acceptable for this audit.

11. Section 3.0 of the Qualification Plan in Sequence 8a, b, and c specifies high and low pressure performance of the main valve. NuScale indicated that the fluid will be at the appropriate pressure and temperature conditions, but that the water will not be borated. NuScale will need to address the qualification of the ECCS valves for borated water conditions to address flashing and boron precipitation effects.

Status: The demonstration of the capability of the ECCS valves to perform with reactor fluid conditions of high temperature and pressure and boration is discussed in this audit report.

12. Section 3.0 of the Qualification Plan in Sequence 8a indicates that a successful qualification flow will be less than the predicted flow. NuScale indicated that the minimum flow is addressed by Sequence 8b and c. NuScale should demonstrate that the minimum flow for adequate recirculation is provided by the qualification plan.

Status: During the onsite audit discussions, NuScale personnel clarified that the qualification testing will demonstrate the minimum flow performance for recirculation of the RRV will be addressed in Sequence 8b. The NRC staff considers this clarification of the Qualification Plan to address minimum recirculation flow of the RRV to be acceptable for this audit.

13. Section 3.0 of the Qualification Plan in Sequence 8b indicates that the RRV will be tested to demonstrate that the C_v flow coefficient criteria are satisfied. NuScale should complete its demonstration of the acceptability of the acceptable range of the C_v flow coefficient specified in Design Specification.

Status: During the onsite audit discussions, NuScale personnel clarified that the Qualification Plan in Sequence 8b will address the acceptability of the full range of the C_v flow coefficient for the RRV, including both flow directions. The NRC staff considers this clarification of the Qualification Plan to be acceptable for this audit.

14. Section 3.0 of the Qualification Plan in Sequence 8c indicated that the RVV will be tested with extrapolation of flow results to be justified by analysis to demonstrate that the flow is within the acceptable bounds. NuScale should provide guidance to justify the acceptable demonstration of the flow performance of the RVV to perform its safety function.

Status: During the onsite audit discussions, NuScale personnel indicated that the extrapolation of flow results during the qualification of the RVV will be justified. The NRC staff notes that the QME-1 requirements for the extrapolation of valve qualification are provided in Paragraph QV-7462, "Extrapolation of Qualification to Another Valve Assembly." Therefore, the qualification of the valve assembly should be described in the Functional Qualification Report in accordance with Subsubarticle QV-8310, "Functional Qualification Report," in ASME QME-1-2007.

15. Section 3.0 of the Qualification Plan in Sequence 10 describes the functional testing for the IAB valve over a range of hydraulic fluid conditions to be applied to both the RVV and RRV. NuScale will need to address the qualification of the IAB valves in the ECCS valves for borated water conditions to address flashing and boron precipitation effects. In addition, NuScale will need to address the qualification of application of the IAB valve tests for both the RVV and RRV.

Status: During the onsite audit discussions, NuScale personnel stated that the qualification testing of the IAB valve will include high temperature and pressure water without boration. The demonstration of the design capability of the IAB valve to support the DC review is discussed in this audit report.

16. The Qualification Plan does not discuss post-installation testing specified in ASME QME-1-2007, Subsubarticle QV-7470, "Post-Installation Verification and IST Baseline," for the ECCS valves. NuScale should address its plans to satisfy the QV-7470 provisions.

Status: During the onsite audit discussions, the NRC staff described the post-installation testing requirements specified in Subsubarticle QV-7470 of ASME QME-1-2007. Based on those discussions, NuScale plans to address the post-installation testing requirements in the Qualification Plan. The NRC staff considers this planned update of the Qualification Plan to be acceptable for this audit.

17. Section 4.0 of the Qualification Plan concludes that the Qualification Plan is intended to demonstrate how Target Rock plans to demonstrate that the ECCS valves have been designed and qualified in accordance with the design specification and ASME QME-1 Standard. Based on the comments on the qualification of the subcomponents of the ECCS valves, NuScale should address the design demonstration testing of the ECCS valves to support the DC application.

Status: This audit report indicates the remaining issues for the demonstration of the design of the ECCS valves to support the DC application.

18. The Qualification Plan should discuss plans for batch testing of individual parts of the ECCS valves, such as bellows, springs, tubing, rods, filters, and bolts, to provide reasonable assurance in their capability to perform the applicable design-basis functions.

Status: During the onsite audit discussions, Target Rock personnel stated that the individual parts will be demonstrated (such as by batch testing) before being included in qualification testing. The NRC staff considers this clarification to be acceptable for this audit.

Technical Manuals

NuScale provided several Technical Manuals for the ECCS valves in its eRR during this audit. The NRC staff will compare these technical manuals to the final design features of the ECCS valves during a future audit for any remaining follow-up items.

Preliminary ASME Design Reports

NuScale provided preliminary ASME design reports for the ECCS valves in its eRR during this audit. The NRC staff will review the ASME design reports in comparison to the final design features of the ECCS valves during a future audit for any remaining follow-up items.

Initial ECCS Valve Audit Report Follow-Up Items

1. NuScale stated that the valve supplier (Target Rock) has conducted calculations and analyses to support the design and performance of the ECCS valves, including the main valve, IAB valve, trip valve, and reset valve. For example, NuScale stated that the Target Rock calculations and analyses include the following:

a) sizing and flow capacity calculations for the ECCS main valve, including assumptions for set pressure, overpressure, temperature, flow rate, backpressure, flow coefficient (C_v), pressure drop ratio factor (X_T), and appropriate correction factors;

b) force balance on the main disc during the stages of actuation;

c) evaluation of the performance of the main valve with a control orifice and filter intended to allow the main chamber to achieve and maintain full reactor pressure condition during plant operation;

d) evaluation of the temperature effects in the sizing of the four valve subcomponents of the ECCS valve from normal room temperature to the operating conditions of each subcomponent; and

e) summary analysis report of the ECCS valve design.

NuScale stated that the detailed design documentation is maintained at the valve supplier facility. The NRC staff plans to review the ECCS valve calculations and analyses at the valve supplier facility as part of its evaluation of the design of the ECCS valve and its subcomponents.

Status: During the onsite audit, the NRC staff discussed the calculations and documentation for the ECCS valves with NuScale and Target Rock personnel. Specific comments on the calculations and documents are provided in this audit report. NuScale should confirm that the Target Rock calculations and documentation are finalized as quality assurance products for the final design of the ECCS valves to support the DC application.

2. NuScale stated that the ECCS valve will be designed such that the main valve will move to its full open position in a timely manner upon actuation, and remain in the full open position throughout its required operation. The NRC staff will review the FMEA to evaluate the potential failure modes of the ECCS valve (including its four valve subcomponents) when made available by NuScale during a future audit.

Status: During the onsite audit, the NRC staff discussed the FMEA with NuScale and Target Rock personnel. The staff indicates the remaining FMEA review items in this audit report.

3. NuScale Design Drawing NP12-00-B020-M-GA-2617, “Reactor Vent Valve Drawing,” identifies the RVV as Nominal Pipe Size (NPS) 5 with a specific inlet diameter and a specific discharge diameter. NuScale FSAR Tier 2, Section 6.3, “Emergency Core Cooling System,” specifies the RVV as a 6-inch valve. NuScale Design Drawing NP12-00-B020-M-GA-2650, “Reactor Recirculation Valve Drawing,” identifies the RRV as NPS 2 with a specific inlet diameter and a specific discharge diameter. NuScale FSAR Tier 2, Section 6.3 specifies the RRV as a 4-inch valve. The NRC staff will evaluate the differences between the FSAR descriptions and design drawings for the RVVs and RRVs.

Status: During the onsite audit, the NRC staff discussed the current design of the RVVs and RRVs with NuScale and Target Rock personnel. The resolution of the design size of the RVVs and RRVs is indicated in this audit report.

4. NuScale Design Drawings NP12-00-B020-M-GA-2617 and NP12-00-B020-M-GA-2650 specify a filter assembly installed in the orifice between the reactor coolant pressure and main valve control chamber for both the RVV and RRV, respectively. The NRC staff will evaluate the

demonstration by NuScale that the filter assembly will not impact the capability of the RVV and RRV to perform their safety functions.

Status: During the onsite audit, the NRC staff discussed the filter assembly in the main valve with NuScale and Target Rock personnel. The staff indicates the remaining review items related to the filter assembly in this audit report.

5. NuScale Design Drawing NP12-00-B020-M-GA-2617 indicates a diffuser assembly is installed near the discharge of the RVV. NuScale stated that the full assembly, including the diffuser, will undergo design testing to demonstrate the performance of the ECCS valves. The NRC staff will evaluate the design test setup, performance, and results for the potential impact of the diffuser assembly on the performance of the ECCS valves.

Status: During the onsite audit, the NRC staff discussed the RVV diffuser assembly with NuScale and Target Rock personnel. The staff indicates the remaining review items related to the RVV diffuser assembly in this audit report.

6. NuScale stated that the design of the IAB valve is consistent with the description in the response to RAI 8815 (Question 15-2) provided in the NuScale letter dated July 21, 2017. The RAI response states that the top of the rod is kept off the vent line seat by the pressure of the fluid in the control chamber and the vent line. However, the rod appears to be maintained in the open position by the IAB spring force. The rod will move against the vent line seat when the differential pressure between the reactor coolant system and the vent line is sufficient to overcome the IAB spring force. The NRC staff will review the final design of the IAB valve for consistency with the description in the RAI response.

Status: During the onsite audit, the NRC staff discussed the design of the IAB valve with NuScale and Target Rock personnel. The staff indicates the remaining review items related to the design of the IAB valve in this audit report.

7. NuScale stated that the ongoing detailed design evaluation of the IAB valve will provide reasonable assurance of the closure of the vent port in a timely manner to prevent the main valve chamber from losing pressure such that the main valve would open (fully or partially) prior to the differential pressure between the RPV and CNV being reduced to the specified value. The NRC staff will review the final design of the IAB valve for its performance characteristics during a future audit.

Status: During the onsite audit, the NRC staff discussed the operation of the IAB valve with NuScale and Target Rock personnel. The staff indicates the remaining review items related to the performance of the IAB valve in this audit report.

8. NuScale stated that the ongoing detailed design evaluation of the IAB valve will provide reasonable assurance of the sealing requirements for the vent port to prevent leakage from the main chamber prior to the differential pressure between the RPV and CNV being reduced to the assumed value for main valve opening. NuScale Drawing Document NP12-00-B020-M-GA-5679, “Inadvertent Actuation Block Drawing,” identifies the IAB valve assembly as a Category A valve in accordance with the IST program requirements in the ASME “Code for Operation and Maintenance of Nuclear Power Plants” (OM Code). NuScale stated that it will evaluate the IAB valve categorization in the NuScale IST Program to satisfy the ASME OM Code regarding leakage requirements. The NRC staff will review the final design of the ECCS valve (including the IAB valve) to support its IST categorization.

Status: During the onsite audit, the NRC staff discussed the sealing requirements of the IAB valve with NuScale and Target Rock personnel. The most recent design drawing of the IAB valve assembly has downgraded the leakage categorization of the IAB valve. Upon completion of the final design of the IAB valve, NuScale should confirm that the leakage categorization of the IAB valve is consistent with its performance requirements.

9. NuScale stated that the orientation of the trip and reset valves for the RVVs and RRVs might not match the orientation indicated in NuScale FSAR Tier 2, Figure 6.3-3, “Emergency Core Cooling System Valve and Actuator Hydraulic Schematic,” on page 6.3-27. NuScale stated that the actual design will have the reset valve on the top of the assembly, and the trip valve on the bottom of the assembly, to allow gravity to assist in the operation of each valve. The NRC staff will verify this orientation in final design drawings of the NuScale ECCS valves.

Status: During the onsite audit, NuScale personnel clarified the planned orientation of the trip and reset valves for the RVVs and RRVs. The NRC staff considers this clarification to be acceptable for this audit.

10. NuScale stated that the four ECCS valve subcomponents will not be designed to allow adjustments following installation. NuScale stated that shims will be installed in the ECCS valve to adjust its performance during pre-installation testing. NuScale Drawing Document NP12-00-B020-M-GA-5679 specifies that shims will be installed between the spring and disc to achieve the IAB threshold and IAB release pressures within the specification requirements. NP12-00-B020-M-GA-5679 specifies that the IAB threshold pressure will be set between 1100 and 1200 psid, and that the IAB release pressure will be set between 1000 and 1100 psid, at the factory. The NRC staff will review the design of the ECCS valves (including shims and their precision) to account for variations between pre-installation testing and normal operating conditions.

Status: During the onsite audit, the NRC staff discussed the shim to be included in each IAB valve with NuScale and Target Rock personnel. As part of the final design of the ECCS valves, NuScale should demonstrate that the shims are capable of accounting for variations between pre-installation testing and normal operating conditions.

11. NuScale stated that only position indication of the main valve and trip/reset valves will be monitored to demonstrate the operational readiness of the ECCS valves. The NRC staff will review the design of the ECCS valves to provide reasonable assurance of operational readiness of the ECCS valves (including operation of the IAB valve).

Status: During the onsite audit, the NRC staff discussed the position indication provisions for the main valve and trip/reset valves. NuScale personnel indicated that the position indication assembly for the main valve is being upgraded to be able to perform at high temperature conditions. The upgrade of the main valve position indication assembly is discussed in this audit report.

12. NuScale stated that the trip/reset lines and control chamber of the ECCS main valve will be filled with borated water from the CVCS during initial setup prior to plant startup. When the trip valve is opened, hot borated water will flash to steam in the main control chamber, IAB valve, and trip line. The NRC staff will review the design of the ECCS valves to provide reasonable assurance that the flashing of hot borated water and boron deposits will not interfere with the reliability and timeliness of the operation of the NuScale ECCS valves.

Status: During the onsite audit, the NRC staff discussed the performance of the ECCS valves with hot pressurized borated water with NuScale and Target Rock personnel. The staff

indicates the remaining review items related to the fluid conditions for the ECCS valves in this audit report.

13. The NRC staff reviewed NuScale Report ER-B020-3817 on proof-of-concept (POC) testing prepared by the valve supplier in 2015 and made available by NuScale during this initial audit. The test report stated that the testing demonstrated the viability of the ECCS valve design, and the expected operation of the disconnected pilot concept and the IAB feature, in this first-of-a-kind engineering (FOAKE) design for the ECCS valves. However, there were several significant differences between the configuration and conditions for the valves used in the POC testing and the ECCS valves. Some of the differences are as follows:

a. The main valve used for the POC testing was a 2-inch Y-pattern globe valve. In the original design information, the main valves for the NuScale RVVs are specified as 6-inch 90° globe valves and for the RRVs are specified as 4-inch 90° globe valves in NuScale FSAR Tier 2, Section 6.3, and associated design drawings.

b. The valve configuration used for the POC testing included a main valve separate from the IAB valve. The IAB valve used for the POC testing was indicated to be fully representative of the design of the IAB valve for the ECCS valves. In that test configuration, the high pressure to simulate the reactor coolant system entered the IAB valve directly below the IAB rod. NuScale Design Drawing NP12-00-B020-M-GA-5679 shows the IAB valve to be directly attached to the main valve with the reactor coolant system pressure to enter the IAB valve from the side to surround the rod bellows.

c. The trip valve used for the POC testing had a solenoid-operated valve (energize to open) with a very small seat diameter for the water tests and a manual ball valve for the air tests. The trip valve planned for the ECCS valves is a solenoid-operated valve (energize to close) with a larger seat diameter.

d. The trip line configuration used in the POC testing provided a smaller elevation difference between the trip valve and IAB valve than will be present in the actual NuScale reactor. In addition, the fluid volume in the trip line configuration for the POC testing was less than will be present in the actual NuScale installed configuration.

e. The accumulator used for the POC testing had significantly less volume for the main valve pressure than will be present in the NuScale RPV. The pressures applied in the POC testing were not always consistent with the actual pressures for operation of the ECCS valve and its subcomponent valves. The POC testing resulted in accumulator pressure reduction during the tests more significant than would occur during the actual ECCS valve operation. In addition, the POC testing provided the trip line exhaust to atmospheric conditions rather than the CNV conditions.

The NRC staff will evaluate the design testing of the ECCS valves to demonstrate the safety features of the ECCS valves for the actual valve design, configuration, and operating and design-basis conditions.

Status: During the onsite audit, the NRC staff discussed the POC testing with NuScale and Target Rock personnel. The staff indicates the remaining review items related to the POC testing to support the demonstration of the design of the ECCS valves in this audit report.

14. The report of the POC testing concluded that, overall, the test program was highly successful and proved that the proposed ECCS valve design can operate as designed.

However, the test report identified several key aspects to be addressed during the detailed design and testing such as the following:

a. Sizing of the trip valve is critical for the trip valve to adequately vent the trip line to allow operation of the main valve and to allow the IAB valve to immediately seat to prevent premature opening of the main valve.

b. Sizing of the trip line, fittings, and orifice is critical to adequately vent the trip line.

c. In that the proof-of-concept testing included only air and water tests, the effects of hot water, steam, and flashing will need to be assessed.

d. The effect on valve performance from the differences between test facilities and the RPV will need to be assessed.

The NRC staff will evaluate the design testing of the ECCS valve (including its four valve subcomponents) to address the issues identified during the POC testing and issues identified during the detailed design process and NRC staff audit findings.

Status: During the onsite audit, the NRC staff discussed the POC test with NuScale and Target Rock personnel. The staff indicates the remaining review items related to the POC testing to support the demonstration of the design of the ECCS valves in this audit report.

15. In its response to RAI 8820, dated August 1, 2017, NuScale specified the schedule for the availability of ECCS valve design documents as follows: design drawings (October 2017), FMEA (December 2017), qualification plan (December 2017), test plans (May 2018), and initial tests and analyses (December 2019). NuScale was not able to make available the FMEA and qualification plan for the ECCS valves for review during this audit. The NRC staff will review these documents supporting the design of the ECCS valves during a future audit.

Status: During the onsite audit, the NRC staff discussed the FMEA and Qualification Plan for the ECCS valves with NuScale and Target Rock personnel. The staff indicates the remaining review items related to the FMEA and Qualification Plan to support the demonstration of the design of the ECCS valves in this audit report.

16. In its response to RAI 8820, NuScale stated that the justification of the IAB valve as a passive mechanical component is provided in the response to RAI 15-2. The NRC staff reviewed the NuScale response to RAI 15-2 (dated July 21, 2017) and determined that the information is not sufficient to justify the IAB valve as a passive device consistent with the Commission policy. For example, Commission Paper SECY-77-439 (dated August 17, 1977), "Single Failure Criterion," specified that simple check valves could be considered passive components in the then-current operating plant designs. Commission Paper SECY-94-084 indicated that check valves in new reactors with passive cooling systems might not be justified as passive components, because the driving head to open check valves in passive cooling systems might rely on gravity rather than pump flow. SECY-94-084 specified that a failure probability on the order of 1E-4 per year or less would be low enough to be considered a passive failure. Commission Paper SECY-05-138 (dated August 2, 2005), "Risk-Informed and Performance-Based Alternatives to the Single-Failure Criterion," described the NRC consideration of passive components in nuclear power plants. The NRC staff will review the design tests and analyses to justify the IAB valve as a passive component consistent with Commission policy during a future audit.

Status: During the onsite audit, the NRC staff discussed the NuScale assumption of the IAB valve as passive component with respect to the single failure criterion with NuScale and Target Rock personnel. Within the body of this audit report, the staff indicates the remaining items related to the passive component assumption for the IAB valves that NuScale will need to address to support the demonstration of the design of the ECCS valves.

17. In its response to RAI 8820, NuScale stated that the ECCS valves will be designed in accordance with the ASME BPV Code, including capacity certification, with ASME design reports developed in accordance with COL items. The NRC staff conducted a Phase 1 audit of the ECCS valve design specifications and provided comments to NuScale. NuScale stated that the Phase 1 audit comments have been addressed in the ECCS valve specifications and will be available for review in early 2018. The NRC staff will conduct a follow-up audit of the design specifications to verify that the comments have been addressed to support the design of the ECCS valves.

Status: The NRC staff is conducting a follow-up audit of the NuScale design specifications, including the ECCS valve design specification.

18. In its response to RAI 8820, NuScale summarized the proposed FSAR Tier 1 inspections, tests, analyses, and acceptance criteria (ITAAC) for the ECCS valves.

Status: The NRC staff is reviewing the ITAAC for the ECCS valves through a separate RAI process.