U.S.NRC
United States Nuclear Regulatory Commission
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Presentation to the Advisory Committee on Reactor Safeguards Subcommittee

Staff Review of NuScale's US460 Standard Design Approval Application Final Safety Analysis Report, Revision 1

Chapter 3, Sections 3.7, 3.8, 3.9.2

February 4, 2025
(Open Session)

NuScale SDAA FSAR Chapter 3 Review

(Sections 3.7, 3.8, 3.9.2)

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NuScale SDAA FSAR Chapter 3 Review

(Sections 3.7, 3.8, 3.9.2)

Overview

- NuScale submitted Chapter 3, “Design of Structures, Systems, Components and Equipment,” Revision 1, of the NuScale SDAA FSAR on October 31, 2023.
- NRC performed a regulatory audit as part of its review of Chapter 3, from March 2023 to June 2024.
- Questions raised during the audit were resolved within the audit. All RAI responses were acceptable.
- Staff completed the review of Chapter 3 (Sections 3.7, 3.8, 3.9.2) and issued an advanced safety evaluation to support the ACRS meeting.
- Since providing draft SE to ACRS on 1/4/2025, **Section 3.7** was updated regarding acceptability of strong-motion time history being less than 6 seconds; **Section 3.8** was updated regarding demand over capacity ratio (DCR) values for Reactor Building (RXB) calculated and assessed by both element-based and panel section-based approaches.

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NuScale SDAA FSAR Chapter 3 Review

- 3.7 – Seismic Design
  - Section 3.7.1 – Seismic Design Parameters
  - Section 3.7.2 – Seismic System Analysis
  - Section 3.7.3 – Seismic Subsystem Analysis
  - Section 3.7.4 – Seismic Instrumentation
- 3.8 – Design of Category I Structures
  - Section 3.8.1 – Concrete Containment (N/A)
  - Section 3.8.2 – Steel Containment
  - Section 3.8.3 – Concrete and Steel Internal Structures of Steel or Concrete Containments (N/A)
  - Section 3.8.4 – Other Seismic Category-I Structures
  - Section 3.8.5 – Foundations
- Section 3.9.2 – Dynamic Testing and Analysis of Systems, Structures, and Components

Section 3.7.1 – Seismic Design Parameters

Significant Differences Between NuScale DCA and SDAA:

1. <u>Structural Damping Values Used in Seismic Analysis:</u>

- ❖ DCA used reinforced concrete (RC) for safety-related structures and applied a uniform 4% damping for both cracked and uncracked RC members to generate in-structure response spectra (ISRS).
- ❖ SDAA used RC and steel-plate composite (SC) for safety-related structures, utilizing a hybrid damping scheme to generate ISRS; 7% and 5% for cracked RC and SC, and 4% and 3% for uncracked RC and SC, respectively.
- ❖ In both cases, cracked and uncracked ISRS are enveloped to establish design-basis ISRS.
- ❖ Staff finds the SDAA damping values (percent of critical damping) for both cracked and uncracked RC and SC cases acceptable, as they align with the guidance in RG 1.61, "Damping Values for Seismic Design of Nuclear Power Plants."

Section 3.7.1 – Seismic Design Parameters

Significant Differences Between NuScale DCA and SDAA:

2. Supporting Media for Seismic Category I Structures:

- DCA considered four supporting media types: soft soil, firm soil/soft rock, rock, and hard rock.
- SDAA, by contrast, utilized three supporting media types: soft soil, rock, and hard rock.
- In both cases, seismic responses for each soil type were enveloped to generate the design-basis seismic demand.
- Staff finds the SDAA supporting media for Seismic Category I structures acceptable, as they adequately represent the range of expected site soil conditions.

Section 3.7.2 – Seismic System Analysis

Significant Differences Between NuScale DCA and SDAA:

1. Different Methodologies for Seismic Soil-Structure-Fluid Interaction (SSFI) Analysis:
   - DCA employed a two-step methodology to address SSFI effects, involving separate soil-structure interaction and fluid-structure interaction analyses, which included simplifications and approximations.
   - SDAA adopted a single, integrated methodology to evaluate SSFI effects under design-basis ground motion.
   - SDAA methodology is based on Topical Report (TR-0118-58005), "Improvements in Frequency Domain Soil-Structure-Fluid Interaction Analysis," which was approved in 2022.
   - Staff verified that seismic SSFI analysis for US460 standard design was performed in compliance with the applicable limitations and conditions specified in the approved topical report.

Section 3.7.2 – Seismic System Analysis

Significant Differences Between NuScale DCA and SDAA:

2. <u>Different Analysis Models Due to Design Changes:</u>

❖ SDAA incorporates significant design changes from DCA, including six NPMs, updated NPM models, resized UHS, relocated CRB, and new SC walls.

❖ DCA employed a Triple Building Model (including RXB, CRB, and RWB) for design-basis seismic demand calculations, whereas SDAA used a Double Building Model (including RXB and RWB) with an independently modeled CRB.

❖ Staff determined that updated models used in seismic system analysis for US460 standard design are acceptable, as they adhere to applicable industry standards and DSRS acceptance criteria.

Section 3.7.2 – Seismic System Analysis

Significant Differences Between NuScale DCA and SDAA:

3. <u>Different Approaches to Addressing the Results of Parameter Sensitivity Studies:</u>

❖ Both DCA and SDAA conducted in-structure response spectrum (ISRS) sensitivity studies to evaluate parameter variations, including structure-soil separation, empty dry dock, and modularity.

❖ In both cases, the soil-separation scenario resulted in a noticeable exceedance of the design-basis ISRS.

❖ DCA addressed this exceedance by including a COL Item, requiring that site-specific ISRS in soil-separation conditions be demonstrated to remain bounded by the DCA design-basis ISRS.

❖ SDAA addressed the exceedance differently, incorporating the soil-separation scenario into the design-basis ISRS analysis cases. The staff found this approach acceptable, as it directly integrates soil-separation effects into the design basis.

Section 3.7.3 – Seismic Subsystem Analysis

Significant differences between NuScale DCA and SDAA:

- Seismic Analysis of Buried Seismic Category I Piping, Conduits, and Tunnels:
  - DCA did not include buried piping or conduits, and the tunnel connecting RXB and CRB was analyzed as part of CRB.
  - SDAA, however, included an underground reinforced-concrete duct bank containing conduits that connect RXB and CRB.
  - Staff determined the seismic analysis of SDAA buried Seismic Category I structures and systems is acceptable, as it was conducted in accordance with applicable industry standards and DSRS acceptance criteria.

Section 3.8 - Design of Category I Structures

(Control Building (CRB) and Reactor Building (RXB))

- **Section 3.8.1 - Concrete Containment: N/A**
- **Section 3.8.2 - Steel Containment**
  - Significant differences between NuScale DCA FSAR and SDAA FSAR include:
    - Reconfigured boundary condition between the bottom heads of CNV and RPV.
    - Design parameter
      - /operating parameters: (50 psig/1,200 psig/600 °F vs. 60 psig/1,050 psig/550 °F)*

    **(external design pressure/internal design pressure/design temperature)*
  - SDAA SE conclusion is the same as DCA SE conclusion.

Section 3.8.4 - Other Seismic Category I Structures

- Significant differences between NuScale DCA FSAR and SDAA FSAR include:
  - Methodology for the evaluation of seismic Category I and II structures (RXB and CRB) is per the requirements provided in TR-0920-71621-P- A, Rev. 1, "Building Design and Analysis Methodology for Safety-Related Structures."
- SDAA SE conclusion is the same as DCA SE conclusion.

Section 3.8.5 - Foundations

- Significant differences between NuScale DCA FSAR and SDAA FSAR include:
  - The embedment of CRB:
    - » In the SDAA, the CRB is modeled as a surface-founded structure, conservatively ignoring the 5-ft embedment of the foundation for its stability analysis.
    - » In the DCA, the CRB with an embedment depth of 55 feet is modeled as an embedded structure with backfill surround it for its stability analysis.
- SDAA SE conclusion is the same as DCA SE conclusion.

Section 3.9.2 - Dynamic Testing and Analysis of Systems

- Piping Vibration, Thermal Expansion, and Dynamic Effects
- Comprehensive Vibration Assessment Program (CVAP) of Reactor Vessel Internals (RVI) and Steam Generators (SG)
  - Dynamic Response Analysis under Operational Flow Transients and Steady State Conditions
    - TR-121353, Revision 2, “NuScale Comprehensive Vibration Assessment Program Analysis Technical Report”
  - Flow-Induced Vibration (FIV) Validation Testing and Inspection
    - TR-121354, Revision 1, “NuScale Comprehensive Vibration Assessment Program Measurement and Inspection Plan Technical Report”
- Dynamic System Analysis of the RVI and SG under ASME Service Level D Conditions
  - Seismic Loading Analysis
    - TR-121515, Revision 1, “US460 NuScale Power Module Seismic Analysis”
  - Short-Term Transient Loading Analysis
    - TR-121517, Revision 1, “NuScale Power Module Short-Term Transient Analysis”
  - Stress and Deflection Evaluations
    - RAI 10111, Question 3.9.2-1 (Resolved)

Section 3.9.2 – DCA Deferred or Unresolved

- CVAP-Steam Generator Qualification
  - Qualification of SG components due to DWO-induced dynamic loads carveout in the DCA
  - SG validation testing deferred to COL applicant
    - Elimination of significant SG tube FIV not demonstrated
- Service Level D evaluations
  - Did not include hard rock (there is a COL item for site-specific seismic analysis)

Section 3.9.2 – CVAP - Dynamic Response Analysis

- Significant differences between NuScale DCA and SDAA FSARs:
  - Higher flow speeds (25% more power) –> stronger FIV loads
  - Reduced DWO-induced dynamic loads and impacts on SG
  - SG inlet flow restrictors (IFRs) redesigned – no longer at risk for FIV
  - SG tube support system redesigned
  - Secondary flow piping and valve systems redesigned to minimize FIV risk
- SDAA SE conclusion is complete, unlike DCA SE conclusion
  - Qualification of SG due to DWO-induced dynamic loads is no longer a "carveout"
  - TF-3 SG validation testing shows minimal risk of significant FIV

Section 3.9.2 – CVAP – DWO-Induced Loads

- DCA (and early SDAA) concerns:
  - During reverse DWO flow the boiling boundaries in SG tubes might approach the SG inlets leading to:
    - Cavitation erosion
    - Condensation-induced water hammer (CIWH)
  - Significant number of DWO cycles initially allowed over plant life

Section 3.9.2 – CVAP – DWO-Induced Loads

- Three-tiered SDAA safety finding:
  - Boiling boundaries are highly unlikely to approach SG inlets; cavitation and CIWH are therefore highly unlikely
    - Chapter 5 finding confirms NuScale’s analysis methods are acceptable for simulating boiling boundary heights
    - NRC Office of Research independent analysis confirms CIWH is highly unlikely
  - In the unlikely event cavitation or CIWH occurs, NuScale estimates low tube and IFR wear
    - Reduced number of allowable cycles, small loads
  - Finally, the SG inspection program is sufficient to capture any unexpectedly high wear (Section 5.4.1)
    - Full inspection during first refueling outage
    - Afterwards, full inspections over 72 effective full power month intervals

Section 3.9.2 – CVAP – TF-3 SG Validation Testing

- On-site staff audit of facility and flow testing at SIET in Piacenza, Italy in October 2024
  - Facility is a reasonable representation of a partial NPM SG
    - Tightly fitting SG tubes and supports, no need to account for SG support system design differences
  - Test data are sufficient to evaluate risk of significant FIV
- Tested over a comprehensive range of flow rates up to 250% of equivalent NPM 100% power
  - No evidence of Vortex Shedding (VS) or Fluid-Elastic Instability (FEI)

Section 3.9.2 – CVAP – FIV Validation Testing and Inspections

- Significant differences between NuScale DCA and SDAA FSARs include:
  - Replaced internal vibration sensors with dynamic pressure sensors for initial startup testing
- SDAA SE conclusion
  - SG TF-3 testing demonstrated that dynamic pressure sensors should “hear” unexpectedly high RVI or SG vibration during initial startup testing

Section 3.9.2 – Dynamic System Analysis of the RVI and SG under Service Level D Conditions

- Significant differences between NuScale DCA FSAR and SDAA FSAR:
  - Different building, fewer NPMs (6 vs 12)
  - Seismic loads include soft soil and hard rock ground conditions
    - Hard rock events include significant higher frequency loads which align with SG modes of vibration
  - Upper and lower riser interface redesigned
  - RVI hanger plate interface redesigned
  - Different (but improved) modeling approaches

- SDAA SE conclusion is more comprehensive, unlike DCA SE conclusion
  - Thorough assessment of RVI and SG stresses and deflections show minimal risk of damage

Section 3.9.2 – Dynamic System Analysis of the RVI and SG under Service Level D Conditions

- Seismic loads:
  - Simpler, more comprehensive and accurate modeling approach than in DCA
  - Bound all soil types and NPM locations
- Transient loads:
  - Short blow-down events
  - Loads order of magnitude lower than seismic

Section 3.9.2 – Dynamic System Analysis of the RVI and SG under Service Level D Conditions

- RVI stress analyses:
  - Bounding response spectrum method for overall structure
    - Confirmed to be reasonably bounding by comparing to single transient analysis
  - Bounding engineering calculations for joints and simple structures
    - Highly conservative
- SG stress analyses:
  - Full transient analyses for bounding soft soil and hard rock load cases – comprehensive and accurate
- All stresses within allowable limits

NuScale SDAA FSAR Chapter 3 Review

(Sections 3.7, 3.8, 3.9.2)

Conclusion

- While there are some differences between the DCA and the SDAA, the staff found that the applicant provided sufficient information to support the staff's safety finding.
- The staff found that all applicable regulatory requirements were adequately addressed.

Presentation to the Advisory Committee on Reactor Safeguards Subcommittee

Staff Review of NuScale's US460 Standard Design Approval Application Final Safety Analysis Report, Revision 1

Chapter 5

"Reactor Coolant System and Connecting Systems"

February 4, 2025
(Open Session)

NuScale SDAA FSAR Chapter 5 Review

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NuScale SDAA FSAR Chapter 5 Review

Overview

- NuScale submitted Chapter 5, "Reactor Coolant System and Connecting Systems," Revision 1, of the NuScale SDAA FSAR on October 31, 2023
- Responses to Audit questions and RAIs were acceptable
- NRC staff completed the review of Chapter 5 and issued an advanced safety evaluation to support the ACRS Subcommittee meeting
- No significant changes between draft SE provided to ACRS on 1/4/25 and SE submitted on 1/29/25

NuScale SDAA FSAR Chapter 5 Review

Sections

- Section 5.1 – Summary Description
- Section 5.2 – Integrity of Reactor Coolant Boundary
- Section 5.3 – Reactor Vessel
- Section 5.4 – Reactor Coolant System Component and Subsystem Design

NuScale SDAA FSAR Chapter 5 Review

Section 5.2.1 Compliance with Codes and Cases

- Significant differences between NuScale DCA FSAR and NuScale SDAA FSAR include:
  - ASME Codes of Record (2017, vice 2013 BPV/ 2012 OM)
  - Use of ASME Code Cases used (while different, all approved in RGs)
- SDAA SE conclusion same as DCA SE conclusion

NuScale SDAA FSAR Chapter 5 Review

Section 5.2.3 Reactor Coolant Pressure Boundary Materials

- Significant differences between NuScale DCA FSAR and NuScale SDAA FSAR:
  - Lower RPV section flange shell RPV bottom head was SA—508 Grade 3, Class 1 for the DC vs. Lower Vessel (Lower Head, Shell and Flange) is SA-965 FXM-19 for the SDAA. This material is acceptable for ASME Code Class 1 applications
  - Welding material is SFA-5.4 Type E209, E240/SFA-5.9 Type ER 209,ER240 and is compatible to SA-965 FXM-19
  - FXM-19 and Type 2XX weld filler metal specify 0.04 maximum carbon and a Ferrite Number in the range of 5FN to 16FN which meets ASME Code
  - TR-130721 Use of Austenitic Stainless Steel for NPM Lower Reactor Pressure Vessel concludes the US460 SDAA design meets the requirements of GDC 14, GDC 15, GDC 31 and GDC 32
  - Section 5.3 covers additional technical information in more detail

- SDAA SE conclusion same as DCA SE conclusion

NuScale SDAA FSAR Chapter 5 Review

Section 5.3 Reactor Vessel

- Significant differences between NuScale DC FSAR and NuScale SDAA FSAR include:
  - Use of austenitic stainless steel for the lower NPM
  - Exemptions 6 and 7 from ferritic steel requirements inapplicable to austenitic stainless steel lower NPM
    - » Requirements of 10 CFR 50.60; 10 CFR 50.61, and 10 CFR 50 Appendices G (fracture toughness requirements) and H (reactor vessel surveillance program), do not apply to the lower NPM
  - At the COL stage, the final as-built design transients, and material properties of the reactor pressure vessel will be evaluated to confirm that they are bounded by those used in the PTL methodology (SDAA COL Item 5.3-1)

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NuScale SDAA FSAR Chapter 5 Review

Section 5.3 Reactor Vessel (contd.)

- NuScale SDAA SE conclusion is different from NuScale DCA SE conclusion because the SDAA design includes austenitic stainless steel lower NPM instead of ferritic steel lower NPM in the DCA
  - Consequently, the SDAA SE includes granting exemptions from some ferritic requirements for the lower NPM
  - In addition, pressure-temperature limits methodology approval differs (next slide)

NuScale SDAA FSAR Chapter 5 Review

Pressure Temperature Limits Methodology Report

- Significant differences between NuScale DCA FSAR and NuScale SDAA FSAR include:
  - SDAA design is never beltline limited in the lower NPM
  - Pressure-Temperature curves are primarily limited by geometric discontinuities in locations with essentially no neutron embrittlement
  - At the COL stage, the final as-built design transients, and material properties of the reactor pressure vessel will be evaluated to confirm that they are bounded by those used in the PTL methodology (SDAA COL Item 5.3-1)
- SDAA SE conclusion is not the same as DCA SE conclusion because of changes to the design and expanded COL Item 5.3-1

NuScale SDAA FSAR Chapter 5 Review

Section 5.4.1 Steam Generators

- Significant differences between NuScale DCA FSAR and NuScale SDAA FSAR
  - Inlet flow restrictor (IFR) design
    - New center-flow orifice design
    - IFRs expanded against the tube inside surface, not attached to a plate outside the tubes
    - Removed for SG inspection and maintenance activities, including IFR inspection
  - SG Program COL Item 5.4-1 includes additional inspections for first module to undergo a refueling outage
    - 20 percent of the tubes will be inspected during each refueling outage over the 72 effective full-power months after the first refueling outage (100 percent inspection)
  - SG Program technical specifications
    - Structural integrity performance criterion (SIPC) for steady-state full-power operation is based on ASME Code for external pressurization (2xΔP) rather than burst (3xΔP)
    - Tube plugging criterion not changed from [40%] through-wall, but new analysis based on new support design and SIPC

NuScale SDAA FSAR Chapter 5 Review

Section 5.4.1 Steam Generators (Continued)

Approach Temperature Limit for Density Wave Oscillation (DWO) Instability

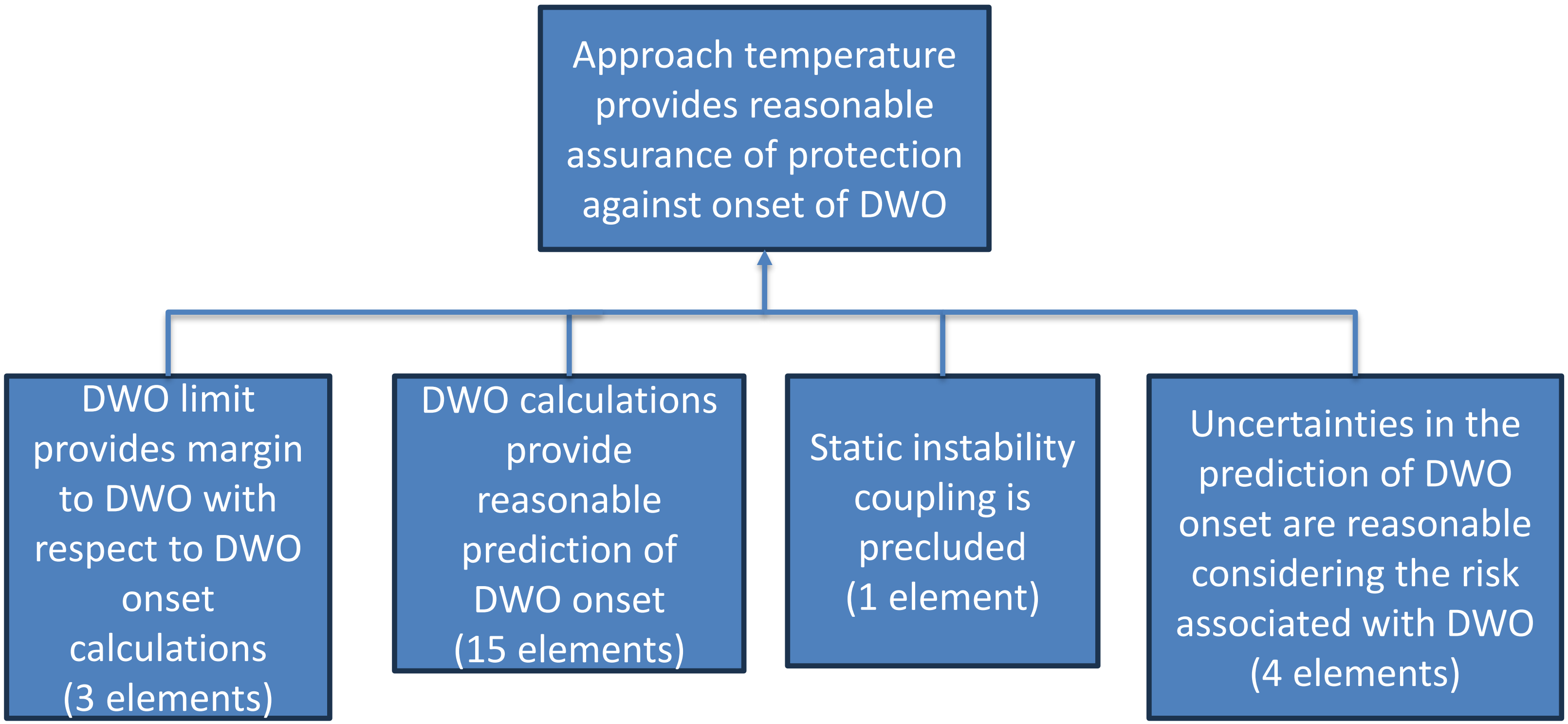
- FSAR Section 5.4.1.3 describes the approach temperature
  - $\Delta T_{approach} = T_{RCS,hot} - T_{SG,exit}$
- Adequacy of approach temperature limit demonstrated through NRELAP5 calculations
  - Approach temperature limit demonstrates margin to DWO onset with respect to NRELAP5 predicted DWO onset

NuScale SDAA FSAR Chapter 5 Review

Section 5.4.1 Steam Generators (Continued)

Approach Temperature Limit Review Framework

- ❖ NRC staff evaluated 23 elements to support finding



NuScale SDAA FSAR Chapter 5 Review

Approach Temperature Limit Review Framework (continued)

5.4.1.4.2.1.1	The approach temperature limit provides margin to DWO with respect to DWO onset calculations
	Approach temperature limit is always reached before DWO onset is predicted to occur
	Calculations cover an adequate range of operating conditions for the NPM steam generators
	Calculations use suitably conservative input

5.4.1.4.2.1.4	Uncertainties in the prediction of DWO onset are reasonable considering the risk associated with DWO
	Consistent with defense-in-depth philosophy
	Maintains sufficient safety margins
	Risk is small and consistent with the intent of the Commission's Safety Goal Policy Statement
	Performance measurement strategies

NuScale SDAA FSAR Chapter 5 Review

Approach Temperature Limit Review Framework (continued)

5.4.1.4.2.1.2	**DWO onset calculations provide reasonable insight into the likelihood of DWO**		
	5.4.1.4.2.1.2.1	The evaluation model contains the adequate modeling capabilities	
		4 elements	
	5.4.1.4.2.1.2.2	The evaluation model has been adequately assessed against experimental data	
		The experimental data used for assessment is appropriate	
			7 elements
		The evaluation model has demonstrated the ability to predict DWO over the analysis envelope	
			4 elements

NuScale SDAA FSAR Chapter 5 Review

Conclusions - Approach Temperature Limit Review

- Approach temperature limit provides reasonable assurance of adequate protection against DWO onset for the SG design
  - Approach temperature limit provides margin to DWO with respect to DWO onset calculations (see SER Section 5.4.1.4.2.1.1)
  - DWO onset calculations provide reasonable insight into the likelihood of DWO (see SER Section 5.4.1.4.2.1.2)
  - Static instability coupling is precluded (see SER Section 5.4.1.4.2.1.3)
  - Uncertainties in the prediction of DWO onset are reasonable considering the risk associated with DWO (see SER Section 5.4.1.4.2.1.4)
- The staff approval of the approach temperature limit does not approve the general use of the NRELAP5 evaluation model for use in DWO calculations
  - Limitation includes the prediction of DWO onset or the prediction of thermal-hydraulic behavior during DWO
  - The staff is unable to determine the adequacy of the evaluation model due to gaps in model assessment (see SER Section 5.4.1.4.2.1.2)

NuScale SDAA FSAR Chapter 5 Review

Section 5.4.3 Decay Heat Removal System

- Notable changes between NuScale DCA FSAR and NuScale SDAA FSAR include:
  - increase in number of condenser tubes, average shorter tube length, lower condenser elevation, lower UHS water level
  - credited in the revised LOCA evaluation model
  - new NRELAP5 basemodel changes related to DHRS such as additional heat structures and changes to pool nodalizations
- SDAA SE conclusion similar to DCA SE conclusion except with inclusion of LOCA-related requirement

NuScale SDAA FSAR Chapter 5 Review

Conclusions

- While there are some differences between the DCA and the SDAA, the staff found that the applicant provided sufficient information to support the staff's safety finding
- The staff found that all applicable regulatory requirements were adequately addressed