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

May 21, 2025

Honorable David A. Wright
Chairman
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT: REPORT ON THE SAFETY ASPECTS OF THE NUSCALE US460 SMALL MODULAR REACTOR STANDARD DESIGN APPROVAL APPLICATION

Dear Chairman Wright:

During the 725th meeting of the Advisory Committee on Reactor Safeguards (ACRS), May 6 through 9, 2025, we completed our review of the NuScale Power, LLC (NuScale or applicant) "NuScale US460 Plant Standard Design Approval Application [SDAA]" for its uprated small modular reactor and the NRC staff's associated advanced Safety Evaluation Report (SER) with no open items. This letter report fulfills the requirement of Title 10 of the *Code of Federal Regulations* (10 CFR) Section 52.141 that "the ACRS shall report on those portions of the application which concern safety." During our review, we had the benefit of interactions with representatives of the NRC staff and the applicant. We also had the benefit of the documents referenced. Appendix I lists the chronology of NuScale Subcommittee and Full Committee meetings and their subjects. Appendix II contains the list of our memoranda on advanced SER chapter reviews approved by the Committee.

CONCLUSIONS AND RECOMMENDATIONS

1. The NuScale US460 small modular reactor is an integrated, natural-circulation, advanced pressurized water reactor. The design incorporates unique passive safety features, providing enhanced margins of safety and long coping times without the need for electrical power or operator intervention.

2. The NuScale US460 SDAA is a complete, well-documented application, backed by validated methodologies and extensive experimental testing. There is reasonable assurance that the plant can be constructed and operated without undue risk to the health and safety of the public.

3. The NRC staff's SER for the NuScale US460 SDAA should be issued.

4. A Standard Design Approval for the NuScale US460 application should be issued.

BACKGROUND

NuScale US460 SDAA

The NuScale US460 is a power uprate of the individual modules of its US600 design certification application (DCA) and consists of up to six NuScale Power Modules (NPMs) in a single reactor building (RXB). Each NPM is a small, integrated, natural-circulation, pressurized water reactor (PWR) composed of a reactor core and riser, a pressurizer, and two helical-coil steam generators (SGs) within a reactor pressure vessel (RPV). The RPV is housed inside a closely fitting steel containment vessel (CNV). This highly integrated design eliminates large-diameter piping to connect the SGs and pressurizer to the reactor vessel. The NPMs are mostly immersed in a large pool of borated water in the RXB, serving as the ultimate heat sink. The modularized system can be moved within the RXB and disassembled/reassembled for refueling.

The reactor core consists of approximately half-length, commercial PWR 17x17 fuel assemblies (37) and control rod assemblies (16), surrounded by a stainless-steel reflector, and is cooled by natural circulation of the borated, light-water primary coolant. Nominal operating conditions, linear heat rate, and fuel burnup are below those of the current PWR operating fleet. Each NPM is rated at 250 MWt (versus 160 MWt for the US600 DCA), with an output of approximately 77 MWe. With the power uprate, the nominal operating pressure of the reactor was raised to 2000 psia. This increase led to several design changes, notably the RPV and CNV design pressures and associated materials selection.

Unique safety features include: (1) a natural circulation decay heat removal system (DHRS) comprised of two independent passive trains, with each train connecting one of the steam generators to a heat exchanger immersed in the RXB pool; and (2) passive emergency core cooling system (ECCS) valves that allow depressurization of the primary system to the CNV, and core cooling by recirculation of the primary coolant from the CNV to the primary system. The RPV and the CNV are sized such that the retained reactor coolant inventory is sufficient to maintain a collapsed liquid level above the height of the core fuel rods for postulated accident scenarios. Both systems provide diverse, passive means of transferring stored energy and decay heat from the reactor systems to the RXB pool. Combined, the DHRS and ECCS designs provide for long coping times (72 hours) without need for electric power or operator intervention.

To address boron dilution and criticality concerns associated with long-term cooling by DHRS and ECCS operation identified during the DCA review, NuScale added additional holes and slots to the NPM core riser to promote boron mixing in the RPV. Additionally, NuScale added an ECCS supplemental boron (ESB) system to assure sufficient boron in recirculating water under extended passive cooling.

Additional US460 design changes include manufacturing the lower RPV shell of austenitic stainless steel rather than low alloy steel used within the legacy PWR fleet. This change in material provides technical justification to support exemptions from requirements related to fracture toughness and material surveillance program requirements, as well as pressurized thermal shock. Notable containment system design improvements include manufacturing the upper CNV and a portion of the vessel below the main flange of martensitic stainless steel and the lower section of the CNV of austenitic stainless steel. These higher strength alloys allow increased design pressure and temperature, resulting in improved containment response design margins.

We noted other important changes incorporated into the US460 design. Venturi flow restrictors were added to the chemical and volume control system inlet and discharge lines to mitigate inventory loss in the event of an unisolable break. The NPM containment isolation valve design configuration has also been modified to include a containment isolation test fixture to better support periodic local leak rate testing. Venturi flow restrictors were also added to the ECCS valves to restrict blowdown flows upon failure or inadvertent opening, reducing pressure and thermal loads on containment. The RXB pool level control band has been lowered to better match the passive heat transfer rate from the CNV to the pool with the decay heat load, and better control the rate of condensation-driven depressurization. Finally, a passive autocatalytic recombiner system was added in the containment of each NPM to eliminate the need for post-accident combustible gas monitoring.

ACRS Review Approach

Like the NRC staff, we conducted a “delta” review of the NuScale SDAA, focusing on safety aspects of the NPM power uprate and major supporting design changes since the DCA and its review. In particular, we examined design changes that affect the primary safety functions of reactivity control, decay heat removal, and confinement of radionuclides, and changes to structures, systems, and components that perform those safety functions. We also reviewed key supporting documentation, including new, revised, or supplemented topical reports and new technical reports that amended the final safety analysis report chapters.

To expedite our review, we assigned members to review individual chapters of the final safety analysis report and the associated advanced SER for new safety-significant items, impacts of the power uprate, or significant design “deltas.” After Subcommittee meeting discussions, assigned members provided chapter reviews for presentation to the full Committee for deliberation and approval. These chapter reviews included the focus areas identified from our DCA review and are discussed below.

Independently, the staff implemented a “high impact technical issues” (HITI) approach to working with the applicant to focus completion of their evaluation. The staff’s use of HITIs complemented our review and provided timely information to address safety-significant technical issues.

Our approach resulted in a 70 percent reduction in the number of meetings with NuScale and the staff, and a reduction in the number of Committee letters from 28 to one compared to our DCA review.

DISCUSSION

The following sections address our overall assessment of the safety of the NuScale SDAA, and discuss specific technical issues, observations, and results from our review, including closure of the focus areas from our DCA review.

Key Safety Features of the NuScale SDAA

The NuScale design provides enhanced margins of safety relative to the current PWR fleet through the following design features:

- Integral Design: Integrating the primary and secondary systems within the RPV eliminates the potential for large piping breaks. The design of the CNV preserves primary coolant inventory to keep the active core covered in potential accident scenarios, without the need for added coolant makeup and injection. Additionally, all major piping penetrations are through the top of the CNV and fitted with double isolation valves.

- Ultimate Heat Sink: The immersion of the NPMs in the RXB pool provides for a robust passive ultimate heat sink. Scrubbing of fission products in this pool would also significantly reduce radiological consequences for hypothetical accidents with core melt scenarios.

- Passive Decay Heat Removal: Each NPM has redundant, independent, closed-loop passive DHRS trains to remove energy from the primary loop through a SG to a heat exchanger immersed in the RXB pool (ultimate heat sink).

- Passive Emergency Core Cooling: The passive ECCS depressurizes the primary system, condenses steam on the CNV inner surface immersed in the RXB pool (ultimate heat sink), and recirculates the retained coolant through the core.

- ECCS Supplemental Boron (ESB) System: After ECCS actuation, the ESB system allows boron contained in baskets in the CNV to dissolve into the recirculating water, minimizing the potential for a return to power or criticality event.

- Smaller Source Term: When compared to a large PWR, the lower core power leads to a lower decay heat level and radionuclide inventory. The lower decay heat level and prevention of core uncovery in design basis events lead to reduced potential for fuel failure.

- No Electrical Power Needed: On loss of power, the design accomplishes its safety functions without need for alternating or direct current power.

- No Operator Actions Required: The design provides long coping times (up to 72 hours) and accomplishes its safety functions without requiring operator intervention.

ECCS and ECCS Valve Performance

In our final US600 DCA letter, the Committee favorably highlighted the passive nature of the NuScale ECCS system but noted that performance of the unique ECCS valve system was one of the most important risk contributors to the probabilistic risk assessment (PRA). The Committee's expectation was that extensive qualification testing planned by NuScale would provide confidence in the ability of the valves to maintain their required performance after extended periods in an operational environment. For the SDAA review, NuScale provided a summary of the completed valve testing, and the staff described their testing oversight and conclusions. Following consideration of this additional information, residual Committee concerns regarding valve operation (opening on demand) are considered resolved.

Helical-Coil Steam Generator Design

The potential for adverse effects from unstable density wave oscillation (DWO), including accelerated tube wear, was a significant unresolved concern to the Committee as reflected in the DCA letter. NuScale has continued to evolve their understanding of DWO and its potential impact on operation of the helical-coil SGs through testing and analysis, leading to adjustments reflected in the US460 design and planned operation. Rather than demonstrate via testing that DWO conditions challenging to system components and operation could be avoided, a DWO management strategy has been adopted for the US460 design. DWO conditions may still be encountered during startup, low power, and other transient operations resulting in a slow accumulation of SG tube damage. Operational conditions favorable to DWO are monitored, and cumulative time operating in this regime will be tracked against a technical specification limit. This, in combination with SG tube inspections, will ensure that SG integrity is not impaired by unacceptable DWO-related damage accumulation. The efficacy of this approach will be further demonstrated during startup and early operation of the lead NPM.

Boron Dilution and Return to Criticality

Maintaining adequate shutdown margin is important to NuScale's strategy for the US460's period of extended passive cooling (i.e., enabling 72 hours of decay heat removal without operator action). We were provided with details related to both design features and evaluation model predictions of shutdown margin. Enhancements in the US460 design, including riser holes at several elevations and boron baskets in the CNV, were found to effectively mitigate stratification and boron dilution. With these design changes in the US460, the exemption to General Design Criterion 27 in the previous US600 design is not requested.

In the NuScale extended passive cooling analyses, the minimum calculated margin to criticality was small; however, NuScale identified several conservative assumptions within their evaluation model. The staff then presented confirmatory computational fluid dynamics analyses used to audit NuScale's calculations and concluded that sufficient boron mixing occurs to maintain subcriticality during and after ECCS actuation. We recommend that NuScale explicitly quantify the conservatisms in their analyses. Furthermore, the Core Operating Limits Report should demonstrate sufficient shutdown margin during the extended period of passive cooling operations for each core reload.

Based on the evidence presented, we consider the staff's conclusion justified and conclude that NuScale resolved the return-to-power concerns that remained from the US600 design.

Source Term (Regarding Post-Accident Combustible Gas Monitoring)

In our US600 DCA review, we were concerned that the proposed post-accident combustible gas monitoring system would risk bypass of containment by opening a substantial-sized line, yet not provide a representative sample of the containment atmosphere. This issue has been addressed in the NuScale SDAA by including a passive autocatalytic recombiner in each NPM to keep oxygen levels below four percent, preventing combustion and ensuring an inert containment atmosphere. This change in approach and design addition supports an exemption request from 10 CFR 50.34(f)(2)(xvii)(C) for combustible gas monitoring.

Probabilistic Risk Assessment

The NuScale US460 design-specific PRA is comprehensive in scope and level of detail. The scope includes Level 1 and Level 2 PRA for internal and external initiating events for both full power and low power and shutdown conditions. The PRA was performed for a single NPM and used to develop quantitative or qualitative risk insights for multiple NPMs on a site. A self-assessment of the PRA was performed to evaluate conformance with industry standards.

The Committee review focused on the design changes and their impact on the differences in the risk profiles between US600 DCA and US460 SDAA. Design changes most relevant to the core damage frequency (CDF) and the large release frequency (LRF) are the changes to ECCS, and addition of venturi flow restrictors to the chemical and volume control system injection and discharge lines. Despite a small increase in the CDF, these changes result in a significant reduction in the LRF. From the LRF perspective, these design changes limit coolant loss from breaks outside of containment and allow mitigating these breaks without a need for operator action or inventory makeup. This greatly diminishes the importance of the previous main contributors to the LRF, and results in the SDAA LRF being negligible.

The Committee agrees with the staff findings that the PRA is of sufficient technical adequacy to support the SDA and that the Commission's CDF and LRF goals have been met with significant margin.

SUMMARY

The NuScale US460 small modular reactor is an integrated, natural-circulation, advanced pressurized water reactor. The design incorporates unique passive safety features, providing enhanced margins of safety and long coping times without the need for electrical power or operator intervention. The NuScale US460 SDAA is a complete, well-documented application, backed by validated methodologies and extensive experimental testing. There is reasonable assurance that the plant can be constructed and operated without undue risk to the health and safety of the public. The NRC staff's SER for the NuScale US460 SDAA should be issued. A Standard Design Approval for the NuScale US460 application should be issued.

We are not requesting a formal response from the staff to this letter report.

Sincerely,

Walter L. Kirchner
Signed by Kirchner, Walter
on 05/21/25

Walter L. Kirchner
Chairman

ENCLOSURES:

APPENDIX I: Chronology of the ACRS Review of the NuScale Power, LLC Application for a Standard Design Approval
APPENDIX II: ACRS Memoranda on Advanced SER Chapters
APPENDIX III: List of Acronyms

REFERENCES

1. U.S. Nuclear Regulatory Commission, "NuScale SDAA Advance Safety Evaluation Reports to Support ACRS Review," April 14, 2025 (Agencywide Documents Access and Management System (ADAMS) Package No. ML25104A222).

2. NuScale Power, LLC, "Submittal of the NuScale Standard Design Approval Application," Revision 2, April 9, 2025 (ADAMS Package No. ML25099A236).

3. Advisory Committee on Reactor Safeguards, "Report on the Safety Aspects of the NuScale Small Modular Reactor," July 29, 2020 (ADAMS Accession No. ML20211M386).

APPENDIX I

CHRONOLOGY OF THE ACRS REVIEW OF THE NUSCALE, LLC APPLICATION FOR THE NUSCALE STANDARD DESIGN APPROVAL

The ACRS review of the NuScale Standard Design Approval (SDA) and its interactions and transcripts of the following ACRS meetings.

Subcommittee/Full Committee	Date	Subject
725th ACRS Meeting	May 6-9, 2025	Standard Design Approval Final Report
NuScale Subcommittee	April 1, 2025	NuScale SDA Application Chapters 1, 4 and 15[1]
NuScale Subcommittee	March 4, 2025	NuScale Non-Loss-of-Coolant-Accident Analysis Methodology and Extended Passive Cooling and Reactivity Control Methodology Topical Reports
NuScale Subcommittee	February 18, 2025	NuScale SDA Application Chapters 6, Section 17.4 and 19
NuScale Subcommittee	February 4, 2025	NuScale SDA Application Sections 3.7, 3.8 and 3.9.2 and Chapter 5
NuScale Subcommittee	January 15, 2025	NuScale SDA Application Chapters 3, 16 and Loss-of-Coolant Accident Evaluation Model Topical Report
NuScale Subcommittee	November 5, 2024	NuScale SDA Application Chapters 3 (except for 3.7, 3.8 and 3.9.2), 8 and 14
NuScale Subcommittee	October 1, 2024	NuScale Power Plant Design Capability to Mitigate Beyond-Design-Basis Events Defined by 10 CFR 50.155 Topical Report
NuScale Subcommittee	August 22, 2024	NuScale SDA Application Chapters 7, 9, 12 and 18
NuScale Subcommittee	March 19, 2024	NuScale SDA Application Chapters 2, 10, 11, 13, 17 and 18
NuScale Subcommittee	February 6, 2024	NuScale Subchannel Analysis Methodology and Rod Ejection Accident Methodology Topical Reports

[1] Every Chapter review had a corresponding review recommendation memorandum by a lead ACRS Member to the Chairman of the ACRS on whether further review was warranted at a subsequent full Committee meeting. These were internal deliberations by the Committee in open session and they almost always did not require presentations by the staff or applicant. These review recommendation memoranda can be found in Appendix II to this letter.

NuScale Subcommittee	February 15, 2023	NuScale SDA Application Update

APPENDIX II

ACRS MEMORANDA ON ADVANCED SER CHAPTERS

Subject	Date	ADAMS Accession Number
Input for ACRS Review of the NuScale US460 Standard Design Approval Application - Safety Evaluation Report for Chapter 1, “Introduction and General Description of the Plant”	May 21, 2025	ML25139A525
Input for ACRS Review of the NuScale Standard Design Approval Application - Safety Evaluation Report for Chapter 2, “Site Characteristics and Site Parameters”	May 9, 2024	ML24124A191
Input for ACRS Review of NuScale Power, LLC, Standard Design Approval Application - Safety Evaluation Report for Chapter 3, “Design of Structures, Systems, Components and Equipment”	April 2, 2025	ML25091A094
Input for ACRS Review of the NuScale US460 Standard Design Approval Application - Safety Evaluation Report With No Open Items for Chapter 4, “Reactor”	May 21, 2025	ML25139A545
Input for ACRS Review of NuScale Power, LLC, Standard Design Approval Application - Safety Evaluation with No Open Items for Chapter 5, “Reactor Coolant System and Connecting Systems”	April 21, 2025	ML25091A117
Input for ACRS Review of the NuScale Standard Design Approval Application - Safety Evaluation with No Open Items for Chapter 6, “Engineered Safety Features”	May 8, 2025	ML25119A006
Input for ACRS Review of NuScale US460 Reactor Standard Design Approval Application - Draft Safety Evaluation for Chapter 7, “Instrumentation and Controls”	October 22, 2024	ML24291A115
Input for ACRS Review of the NuScale US460 Reactor Standard Design Approval Application - Safety Evaluation for Chapter 8, “Electric Power”	May 21, 2025	ML25139A529
Input for ACRS Review of the NuScale Standard Design Approval Application - Safety Evaluation Report for Chapter 9, “Auxiliary Systems”	October 23, 2024	ML24291A117
Input for ACRS Review of the NuScale Standard Design Approval Application - Safety Evaluation Report for Chapter 10, “Steam and Power Conversion System”	May 16, 2024	ML24124A170

Input for ACRS Review of the NuScale Standard Design Approval Application - Safety Evaluation Report for Chapter 11, “Radioactive Waste Management”	May 13, 2024	ML24124A174
Input for ACRS Review of the NuScale Standard Design Approval Application - Safety Evaluation Report for Chapter 12, "Radiation Protection"	October 17, 2024	ML24291A120
Input for ACRS Review of the NuScale Standard Design Approval Application - Safety Evaluation Report for Chapter 13, “Conduct of Operations”	May 9, 2024	ML24124A188
Input for ACRS Review of the NuScale Standard Design Approval Application - Safety Evaluation for Chapter 14, “Initial Test Program and Inspections, Tests, Analyses, and Acceptance Criteria”	April 2, 2025	ML25091A128
Input for ACRS Review of the NuScale US460 Standard Design Approval Application - Safety Evaluation Report for Chapter 15, “Transient and Accident Analyses”	May 20, 2025	ML25139A552
Input for ACRS Review of the NuScale Standard Design Approval Application - Safety Evaluation Report for Chapter 16, “Technical Specifications”	April 2, 2025	ML25091A133
Input for ACRS Review of the NuScale Standard Design Approval Application - Safety Evaluation Report for Chapter 17, “Quality Assurance and Reliability Assurance”	May 16, 2024	ML24124A184
Input for ACRS Review of the NuScale Standard Design Approval Application - Safety Evaluation Report for Chapter 17, Section 17.4, “Reliability Assurance Program”	April 2, 2025	ML25091A135
Input for ACRS Review of the NuScale Standard Design Approval Application - Safety Evaluation Report for Chapter 18, “Human Factors Engineering”	October 28, 2024	ML24291A124
Input for ACRS Review of the NuScale US460 Standard Design Approval Application - Safety Evaluation Report for Chapter 19, “Probabilistic Risk Assessment and Severe Accident Evaluation”	May 9, 2025	ML25119A009

APPENDIX III

LIST OF ACRONYMS

ACRS	Advisory Committee on Reactor Safeguards
CDF	Core Damage Frequency
CNV	Containment Vessel
DCA	Design Certification Application
DHRS	Decay Heat Removal System
DWO	Density Wave Oscillation
ECCS	Emergency Core Cooling System
ESB	ECCS Supplemental Boron
HITI	High Impact Technical Issues
LRF	Large Release Frequency
MWe	Megawatt Electric
MWt	Megawatt Thermal
NPM	Nuclear Power Modules
psia	Pounds Per Square Inch Absolute
PRA	Probabilistic Risk Assessment
PWR	Pressurized Water Reactor
RPV	Reactor Pressure Vessel
RXB	Reactor Building
SDAA	Standard Design Approval Application
SER	Safety Evaluation Report
SGs	Steam Generators

May 21, 2025

SUBJECT: REPORT ON THE SAFETY ASPECTS OF THE NUSCALE US460 SMALL MODULAR REACTOR STANDARD DESIGN APPROVAL APPLICATION

Accession No: ML25136A329 **Publicly Available (Y/N):** Y **Sensitive (Y/N):** N
If Sensitive, which category?
Viewing Rights: ☒ NRC Users or ☐ ACRS only or ☐ See restricted distribution

OFFICE	ACRS	SUNSI Review	ACRS	ACRS	ACRS	ACRS
NAME	MSnodderly	MSnodderly	LBurkhart *(MSnodderly for)*	RKrsek	MBailey	WKirchner
DATE	05/19/25	05/19/25	05/19/25	05/21/25	05/21/25	05/21/25

OFFICIAL RECORD COPY