April 15, 2024 Docket No. 99902078

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
One White Flint North
11555 Rockville Pike
Rockville, MD 20852-2738

SUBJECT: NuScale Power, LLC Submittal of the Approved Version of NuScale Topical Report, “Statistical Subchannel Analysis Methodology Supplement 1 to TR-0915-17564-P-A, Revision 2, Subchannel Analysis Methodology,” TR-108601- P-A, Revision 4

REFERENCES: 1. NRC Letter to NuScale, “Final Safety Evaluation for NuScale Statistical Subchannel Analysis Methodology LTR,” dated February 27, 2024 (ML24058A019)

By referenced letter dated February 27, 2024 (Reference 1), the NRC issued a final safety evaluation report documenting the NRC Staff conclusion that the NuScale topical report “Statistical Subchannel Analysis Methodology Supplement 1 to TR-0915-17564-P-A, Revision 2, Subchannel Analysis Methodology,” TR-108601-P-A, Revision 4, is acceptable for referencing in licensing applications for the NuScale small modular reactor design. Reference 1 requested that NuScale publish the approved version of TR-108601-P-A, Revision 4, within three months or receipt of the letter.

Enclosure 1 contains the approved proprietary version of the report entitled “Statistical Subchannel Analysis Methodology Supplement 1 to TR-0915-17564-P-A, Revision 2, Subchannel Analysis Methodology,” TR-108601-P-A, Revision 4. NuScale requests that the proprietary version be withheld from public disclosure in accordance with the requirements of 10 CFR § 2.390. The enclosed affidavit (Enclosure 3) supports this request. Enclosure 1 has also been determined to contain Export Controlled Information. This information must be protected from disclosure per the requirements of 10 CFR § 810. Enclosure 2 contains the nonproprietary version of the approved topical report package.

This letter makes no regulatory commitments and no revisions to any existing regulatory commitments.

If you have any questions, please contact Wren Fowler at 541-452-7183 or at sfowler@nuscalepower.com.

I declare under penalty of perjury that the foregoing is true and correct. Executed on April 15, 2024.

Sincerely,

Carrie Fosaaen
Vice President, Regulatory Affairs
NuScale Power, LLC

Distribution: Mahmoud Jardaneh, NRC
Getachew Tesfaye, NRC
Stacy Joseph, NRC

Enclosure 1: "Statistical Subchannel Analysis Methodology Supplement 1 to TR-0915-17564-P-A, Revision 2, Subchannel Analysis Methodology," TR-108601-P-A, Revision 4, proprietary version

Enclosure 2: "Statistical Subchannel Analysis Methodology Supplement 1 to TR-0915-17564-P-A, Revision 2, Subchannel Analysis Methodology," TR-108601-NP-A, Revision 4, nonproprietary version

Enclosure 3: Affidavit of Carrie Fosaaen, AF-163416

Enclosure 1:

"Statistical Subchannel Analysis Methodology Supplement 1 to TR-0915-17564-P-A, Revision 2, Subchannel Analysis Methodology," TR-108601-P-A, Revision 4, proprietary version

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Enclosure 2:

“Statistical Subchannel Analysis Methodology Supplement 1 to TR-0915-17564-P-A, Revision 2, Subchannel Analysis Methodology,” TR-108601-NP-A, Revision 4, nonproprietary version

Contents

Section A

From:	Stacy Joseph
To:	Regulatory Affairs
Cc:	NuScale-SDA-720DocsPEm Resource; Griffith, Thomas; Getachew Tesfaye; Mahmoud -MJ- Jardaneh
Subject:	Final Safety Evaluation for NuScale Statistical Subchannel Analysis Methodology LTR (Proprietary)
Date:	Tuesday, February 27, 2024 7:48:52 AM
Attachments:	Final SER Subchannel TR-108601-P PROPRIETARY.pdf Final SER Subchannel TR-108601-P Non-Proprietary.pdf

The NRC staff has prepared a final safety evaluation for TR-108601-P, Revision 4 (ML23310A122). The non-proprietary and proprietary final safety evaluations are enclosed. The NRC staff has found TR-108601-P, Revision 4, to be acceptable for referencing in licensing applications for the NuScale small modular reactor design to the extent specified and under the conditions and limitations delineated in the attached final safety evaluation.

The NRC staff requests that NuScale publish the accepted version of this TR within three months of receipt of this electronic mail. The accepted version shall incorporate this electronic mail and the enclosed final safety evaluation after the title page. It must be well indexed such that information is readily located. Also, it must contain historical review information, including NRC requests for additional information and accepted responses. The accepted version of the TR shall include an "-A" (designated accepted) following the report identification number.

If the NRC's criteria or regulations change such that the NRC staff's conclusion in this electronic mail (that the TR is acceptable) is invalidated, NuScale and/or the applicant referencing the TR will be expected either to revise and resubmit its respective documentation or to submit justification for continued applicability of the TR without revision of the respective documentation.

If you have any questions or comments concerning this matter, I can be reached via e-mail at Stacy.Joseph@nrc.gov. The attached documents are both password protected. Password to follow in a separate email.

Sincerely,

Stacy K. Joseph
Senior Project Manager
USNRC/NRR/DNRL/NRLB

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

TOPICAL REPORT TR-108601-P, REVISION 4,

"STATISTICAL SUBCHANNEL ANALYSIS METHODOLOGY, SUPPLEMENT 1 TO

TR-0915-17564-P-A, REVISION 2, SUBCHANNEL ANALYSIS METHODOLOGY,"

NUSCALE POWER, LLC

Proprietary information pursuant to Title 10 of the *Code of Federal Regulations* (10 CFR) Section 2.390, "Public inspections, exemptions, requests for withholding," has been redacted from this document. Redacted information is identified by blank space enclosed within bolded double brackets, as shown here: **{{ }}**.

1.0 INTRODUCTION

By letter dated December 30, 2021 (Reference 1), as supplemented by letters dated April 25, 2022, December 13, 2022, October 12, 2023, and November 6, 2023 (References 4, 6, 11, and 13 respectively), NuScale Power, LLC (NuScale) submitted a request for review and approval of Topical Report (TR)-108601-P, Revision 4, "Statistical Subchannel Analysis Methodology, Supplement 1 to TR-0915-17564-P-A, Revision 2, Subchannel Analysis Methodology," to the U.S. Nuclear Regulatory Commission (NRC). The purpose of the TR is to establish NuScale's statistical methodology for determining a critical heat flux (CHF) limit. The list of key correspondence between the NRC and NuScale is provided in Table 1 below.

Table 1: List of Key Correspondence

Sender	Document	Document Date	Reference
NuScale	Topical Report, Revision 0	December 30, 2021	2
NRC	Completeness Determination - Request for Supplemental Information	February 28, 2022	3
NuScale	Topical Report, Revision 1	April 25, 2022	4
NRC	Completeness Determination	May 4, 2022	5
NuScale	Topical Report, Revision 2	December 13, 2022	6
NRC	Schedule Letter Update	December 21, 2022	7
NuScale	Topical Report, Revision 3	October 12, 2023	11
NRC	Audit Report	November 1, 2023	12
NuScale	Topical Report, Revision 4	November 6, 2023	13

2.0 REGULATORY EVALUATION

General Design Criterion 10, "Reactor design," of Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50 , "Domestic Licensing of Production and Utilization Facilities," states that the reactor core and associated coolant, control, and protection systems shall be designed with appropriate margin to assure that specified acceptable fuel design limits (SAFDLs) are not exceeded during any condition of normal operation, including the effects of anticipated operational occurrences (AOOs). SAFDLs are those limits placed on certain variables to ensure that fuel does not fail. One such SAFDL is associated with critical boiling transition (CBT), which is defined as a transition from a boiling flow regime that has a higher heat transfer coefficient to a flow regime that has a significantly lower heat transfer coefficient. Because the heat production rate is maintained, the reduction in the heat transfer coefficient results in a surface temperature increase, and if that increase is large enough, the surface may weaken or melt, which, in a nuclear power plant, could result in fuel failure.

In order to ensure that CBT does not occur, NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR [Light-Water Reactor] Edition," Section 4.4, "Thermal and Hydraulic Design," Revision 2 (Reference 8), describes two SAFDLs:

(a) there should be a 95-percent probability at the 95-percent confidence level that the hot [fuel] rod in the core does not experience a DNB [departure from nucleate boiling] or boiling transition condition during normal operation or AOOs
(b) at least 99.9 percent of the fuel rods in the core will not experience a DNB or boiling transition during normal operation or AOOs.

Typically, the SAFDL (a) is associated with pressurized-water reactors and the SAFDL (b) is associated with boiling-water reactors. Demonstrating that such a SAFDL has been satisfied relies on more than justifying that the CBT correlation can accurately predict the phenomena because there are uncertainties in the prediction of CBT that are independent of those uncertainties related to the fidelity of the CBT model. Hence, there needs to be a general methodology in which an approved CBT can be used such that the SAFDL is satisfied. Consistent with the above regulations and guidance, the objective of the NRC staff review in this safety evaluation (SE) is to determine if the use of NuScale's statistical subchannel analysis methodology along with an approved CBT model will ensure that the SAFDL (a) will be satisfied.

3.0 TECHNICAL EVALUATION

The NRC staff previously reviewed and approved NuScale's Subchannel Analysis Methodology (NSAM) in TR-0915-17564-P-A, Revision 2 (Reference 9). As supplement 1 to the NSAM, NuScale modified the NSAM with the addition of a statistical methodology in Revision 0 of its Statistical Subchannel Analysis Methodology (SSAM) in TR-108601-P (Reference 2) and requested that the NRC staff review and approve the SSAM. NuScale supplemented the SSAM in Revision 1 (Reference 4), Revision 2 (Reference 6), Revision 3 (Reference 11), and Revision 4 (Reference 13). Although NuScale requested NRC staff approval of the SSAM, the SSAM submittal does not contain all of the necessary documentation to define the SSAM; instead, that documentation is spread across both the SSAM and the NSAM submittals (Reference 13 and Reference 9, respectively). Specifically, each section/subsection of the SSAM submittal does one of three things:

(1) It references to the corresponding section/subsection in the NSAM and does not modify that section/subsection (i.e., **no change**).

(2) It references to the corresponding section/subsection in the NSAM and not only maintains all of the information in that section/subsection, but also adds additional information (i.e., **supplement**).

(3) It references to the corresponding section/subsection in the NSAM and completely replaces that section/subsection (i.e., **replacement**).

The SSAM submittal does not clearly specify which of these three actions is being taken for each section; therefore, Table 2 below clarifies which action applies to each section of the SSAM submittal.

Table 2: NuScale's Statistical Subchannel Analysis Methodology Documentation

Section	No Change	Supplement	Replacement
2.0	X		
2.1	X		
2.2	X		
2.3	X		
2.4	X		
3.0		X	
3.1	X		
3.2		X	
3.3		X	
3.4		X	
3.5	X		
3.6		X	
3.7			X
3.8	X		
3.9	X		
3.10			X
3.10.1			X
3.10.2	X		
3.10.3			X
3.10.4	X		
3.10.5			X
3.10.6			X
3.10.7			X
3.10.8	X		
3.10.9	X		
3.11	X		
3.12			X
3.13			X
3.14	X		
3.15		X	
4.0	X		
5.0	X		
6.0		X	

Section	No Change	Supplement	Replacement
6.1	N/A[1]		
6.2	N/A[1]		
6.3	X		
6.4		X	
6.4.1			X
6.4.2	X		
6.4.3			X
6.4.4	X		
6.4.5	X		
6.4.6	X		
6.4.7	X		
6.4.8	X		
6.5	X		
7.0		X	
7.1	X		
7.2			X
7.3			X
7.4			X
7.5		X	
8.0		X	

The NRC staff notes that TR-108601-P (the SSAM) does not include updated examples to Sections 6.1, 6.2, 6.3, 6.4.2, 6.4.4 through 6.4.8, and 6.5. As indicated in Section 6.0 of the SSAM, most of these sections are not updated in the SSAM since no changes are needed to their content. However, Section 6.1 and Section 6.2 are identified as "(N/A)" in the table above. Section 6.1 lists input values used in the example calculations in the NSAM. These inputs are defined during the application of the methodology for a specific design. The example calculations in Section 6.4.1 and Section 6.4.3 of the SSAM use input values consistent with the US460 design. Section 6 of the SSAM only recreates the sensitivities impacted by the updates to the radial and axial nodalization. Section 6.2 in the NSAM discusses radial nodalization that is not applicable to the SSAM (see Section 3.7).

No change means that the SSAM and NSAM share the same information. For example, the information contained in Section 7.1 of the SSAM would be identical to that in Section 7.1 of the NSAM. The documentation of this information would not be found in the SSAM submittal (Reference 13), but only in the NSAM topical report (Reference 9).

Supplement means that the SSAM contains all of the information in the NSAM, as well as the additional information provided in the SSAM submittal. For example, the information contained in Section 7.5 of the SSAM would contain all of the information in Section 7.5 of the NSAM as well as that in Section 7.5 of the SSAM submittal. The documentation of this information would be found in the SSAM submittal (Reference 13) and in the NSAM topical report (Reference 9).

[1] Sections 6.1 and 6.2 provide an example calculation using the NSAM and do not prescribe any of the SSAM methodology. Further, the example is not an example calculation of SSAM, hence it is labeled as N/A. However, the example may still be useful in understanding the SSAM.

Replacement means that the SSAM contains no information from the NSAM, and only contains the information in the SSAM submittal. For example, the information contained in Section 7.2 of the SSAM contains no information from Section 7.2 of the NSAM. The documentation of this information would only be found in the SSAM submittal (Reference 13) and would not include any information in the NSAM topical report (Reference 9). This also includes new sections contained in the SSAM and not in the NSAM.

The NRC staff focused its review on the SSAM, including both information in the SSAM submittal (Reference 13) and in the NSAM topical report (Reference 9). Therefore, the NRC staff has formatted this SE to match the outline of both submittals and specifies whether **no change**, **supplement**, or **replacement** applies to the information.

2.0 Background (**No Change**)

The NRC staff previously reviewed and approved the background information in the NSAM topical report (Reference 9). Because this information in the SSAM is the same as that approved in the NSAM, the NRC staff has determined that no additional review is required for the SSAM.

3.0 General Application Methodology (**Supplement**)

The NRC staff previously reviewed and approved the general application methodology in the NSAM topical report (Reference 9). Much of the same methodology approved in the NSAM would be applicable to the SSAM. However, the NSAM was approved for various radial nodalizations (including one-eighth core symmetric nodalization), and many of these radial nodalizations are not intended to be used for the SSAM. Therefore, each subsection of Section 3 is addressed below.

3.1 Nuclear Safety Engineering Disciplines (**No Change**)

The NRC staff previously reviewed and approved the nuclear safety engineering disciplines information in the NSAM topical report (Reference 9). Because this information in the SSAM is the same as that approved in the NSAM, the NRC staff has determined that no additional review is required for the SSAM.

3.2 Core Design Limits (**Supplement**)

The NRC staff previously reviewed and approved NuScale's methodology for core design limits in the NSAM topical report (Reference 9). Much of the same methodology approved in the NSAM would be applicable to the SSAM. The deviation from the approved methodology in the SSAM is the change to the basemodel, which is discussed in Section 3.7. Except for the changes related to the basemodel addressed in Section 3.7 below, because of the applicability of the previous review, the NRC staff has determined that no additional review is required.

3.3 Critical Heat Flux Correlation (**Supplement**)

The NRC staff previously reviewed and approved the CHF application methodology described in the NSAM topical report (Reference 9). Much of the same methodology approved in the NSAM would be applicable to the SSAM. The NSAM discusses an approved CHF correlation (NSP2) and provides the details of that correlation, including its approved domain. The SSAM is not limited to a single CHF correlation but could be used with any approved correlation provided that the five conditions listed in Section 3.3 have been satisfied at a minimum. Any approved CHF correlation would need to be consistent with how the correlation was originally developed (e.g., nodalization, losses/resistances, flow areas, modeling impacting flow patterns, etc.) and changes to that evaluation model not described in the NSAM or SSAM would require additional NRC staff review and approval, which is consistent with NSAM Condition 1 and repeated in Section 4 of the SSAM SE. Because these conditions are consistent with the previous application of CHF correlations, the NRC staff has determined that the CHF application method of the SSAM is acceptable.

3.4 Thermal Margin Results Reporting (**Supplement**)

The NRC staff previously reviewed and approved the thermal margin figures of merit described in the NSAM topical report (Reference 9). The same figures of merit approved in the NSAM would be applicable to the SSAM. Additionally, NuScale clarified that the SSAM can determine the penalty factors using either deterministic or statistical methods. Because the SSAM is primarily a statistical methodology, and the penalty factors are the primary influence on the main figure of merit (the minimum critical heat flux ratio (MCHFR) from the VIPRE-01 calculation) of that methodology, the NRC staff has determined that the figures of merit of the SSAM described in this section are acceptable.

3.5 Geometry Design Input (**No Change**)

The NRC staff previously reviewed and approved the geometry design input information in the NSAM topical report (Reference 9). Because this information in the SSAM is the same as that approved in the NSAM, the NRC staff has determined that no additional review is required for the SSAM.

3.6 Fuel Design-Specific Inputs (**Supplement**)

The NRC staff previously reviewed and approved the fuel design-specific inputs in the NSAM topical report (Reference 9). Much of the same description of inputs approved in the NSAM would be applicable to the SSAM. However, the SSAM does include some modeling changes. These changes are addressed in Section 3.7 of this SE. With the expectation of those differences discussed in Section 3.7 of this SE being adequately addressed, because of the applicability of the previous review, the NRC staff has determined that no additional review is required.

3.7 Basemodel (**Replacement**)

While the NRC staff previously reviewed and approved the basemodel section in the NSAM topical report (Reference 9), this material is not directly applicable to the SSAM due to the changes in the basemodel itself. To perform the review of the basemodel, the staff focused on the three main areas described in the SSAM submittal (Reference 13) and the staff’s evaluation is provided below.

Radial Nodalization

While the NSAM had multiple radial nodalization schemes approved, only one radial nodalization scheme is requested for approval in the SSAM submittal. This scheme models one full assembly at the center of the core with nodalization at the subchannel level. This assembly is surrounded on four sides by other assemblies which are modeled with the nodalization at the lumped subchannel level (i.e., multiple fuel subchannels are lumped into a single subchannel for computation). Each of these assemblies is further surrounded by other assemblies which are modeled with the nodalization at a lumped assembly level (i.e., all subchannels in the fuel assembly are lumped into a single subchannel for computation). This nodalization scheme is similar to the basemodel and the Lump51 model from the one-eighth nodalization approved in the NSAM topical report.

In order to demonstrate that this radial nodalization could accurately capture the critical linear heat generation rate (LHGR), NuScale performed a sensitivity study in Section 6.4.1 of the SSAM submittal (Reference 13). That study demonstrated that the radial nodalization proposed resulted in **{{ }}** compared to a full core radial nodalization. Because of this and because a full core radial nodalization is a radial nodalization approved in the NSAM, the NRC staff has determined that the radial nodalization is acceptable.

Future Changes to Radial Nodalization

NuScale requested the flexibility to make limited changes to the approved radial nodalization depending on the circumstances and given that certain conditions were satisfied. Based on the previously approved radial nodalization in the NSAM, the criteria stated in the SSAM submittal, the understanding that the change would be limited to relative minor changes in the meshing, and the understanding that, consistent with current practice, the resulting nodalization would be symmetric, the NRC staff has determined that limited changes would be acceptable.

Axial Nodalization

In the NSAM topical report (Reference 9), the axial nodalization was refined in the upper portion of the fuel assembly to better resolve the region in which CHF is expected to occur. In Section 6.4.3 of the SSAM submittal (Reference 13), NuScale's sensitivity study demonstrated that a variety of node sizes **{{ }}** result in similar simulations and values of the critical LHGR that are within **{{ }}** of each other. While the **{{ }}** node size has a critical LHGR value that is close to the others, some of the local parameters calculated in this run, **{{ }}** seem far from the other test cases, suggesting that this run should not be considered fully converged.

During the NRC staff's review of the NSAM topical report (Reference 9), for the approved nodalization scheme **{{**

}}

{{

}}

The NRC staff agrees that the nodalization sensitivity study demonstrates that for the simulation performed, the {{ }} nodalization is sufficient to resolve the phenomena impacting CHF. However, the NRC staff also recognizes that the variation between similar node sizes represents an uncertainty. While the single sensitivity study in the SSAM submittal (Reference 13) and the NSAM topical report (Reference 9) has the {{ }} nodalization as being the most conservative, this conservatism is likely to change to a different node size if a different scenario is simulated. Given the variation between the variety of node sizes which can be considered converged solutions of the simulation, the NRC staff has determined that a 1 percent uncertainty would be necessary to be applied to the critical LHGR to account for the impact of nodalization.

In an effort to remove the need to directly address this uncertainty, NuScale investigated whether the {{ }} nodalization always results in a conservative value. NuScale sampled across the application domain and compared the critical LHGR results from the {{ }} axial mesh with those of {{ }} axial mesh. In all instances, the {{ }} axial mesh produced a conservative result compared to the {{ }} axial mesh, and that conservatism was consistent with the NRC staff's determination of a 1 percent uncertainty. Because NuScale's sensitivity study demonstrated that the {{ }} axial mesh always results in a conservative prediction of the critical LHGR by approximately the same magnitude as the staff's estimation of the axial mesh uncertainty, the staff found that using a {{ }} axial mesh would not require a further consideration of the axial mesh uncertainty. Because NuScale is using an axial nodalization that has been demonstrated to be converged by a sensitivity study, is within the general range of axial nodalization of CHF analysis, and results in a conservative prediction of the figure of merit whose conservatism counterbalances the axial mesh size uncertainty, the NRC staff has determined that the axial nodalization is acceptable.

Axial Modeling

NuScale changed the axial domain compared to that used in the NSAM topical report (Reference 9). For the SSAM, the VIPRE model extends from the bottom of the lower core plate to above the upper core plate (whereas in the NSAM, the top of the lower core plate and the bottom of the upper core plate defined the boundaries of the VIPRE model). In this modeling extension, NuScale focused specific attention on ensuring an accurate estimation of the crossflow lateral losses in these newly encompassed sections. Because these new geometries are within the capability of VIPRE-01 to model and because NuScale ensured that the crossflows in these new geometries were adequately calculated and that the lateral loss terms of these new geometries had minimal impact on the MCHFR, the NRC staff has determined that the new axial modeling is acceptable.

3.8 Boundary Conditions (**No Change**)

While NuScale has changed the modeling boundary of the SSAM compared to the NSAM by including of the flow through both core plates, many of the boundary conditions themselves remain unchanged.

Inlet Flow

The NRC staff previously reviewed and approved NuScale's methodology for calculating the mass inlet flow rate in the NSAM topical report (Reference 9). This inlet flow rate is based on the total core flow minus the flow lost to the bypass. Because the methodology applied in the SSAM is the same methodology as that approved in the NSAM, the NRC staff has determined that no additional review is required for the SSAM.

Inlet Enthalpy

The NRC staff previously reviewed and approved NuScale's methodology for calculating the inlet enthalpy in the NSAM topical report (Reference 9). Because the methodology applied in the SSAM is the same methodology as that approved in the NSAM, the NRC staff has determined that no additional review is required for the SSAM.

System Pressure

The NRC staff previously reviewed and approved NuScale's methodology for calculating the system pressure in the NSAM topical report (Reference 9). Because the methodology applied in the SSAM is the same methodology as that approved in the NSAM, the NRC staff has determined that no additional review is required for the SSAM.

Bypass Flow

The NRC staff previously reviewed and approved NuScale's methodology for calculating the bypass flow in the NSAM topical report (Reference 9). Because the methodology applied in the SSAM is the same methodology as that approved in the NSAM, the NRC staff has determined that no additional review is required for the SSAM.

Inlet Flow Distribution

In Section 3.7.3 of the SSAM submittal (Reference 13), NuScale identified a change to the inlet flow distribution. In the NSAM topical report (Reference 9), the inlet flow distribution was at the bottom of the fuel pins. However, due to the change in the boundaries of the model, the inlet flow distribution for the SSAM is applied at the bottom of the lower core plate. Applying a reduction to the inlet flow at the bottom of the fuel pins has a much larger impact on CHF performance than applying that same reduction at the bottom of the lower core plate, as the flow is given significantly more time to equalize, and the penalty diminishes greatly before the flow enters the fuel pins.

NuScale provided additional justification that the modeling of the fuel assembly in the region below the fuel pins was adequate. In Section 3.7.3 of the SSAM submittal, NuScale provided a discussion of the crossflow in the newly modeled portions of the assembly (i.e., core plate and bottle nozzle). That analysis demonstrates **{{** **}}** in the fuel bottle nozzle has a minimal impact on the figure of merit. Further, NuScale performed a sensitivity analysis in Section 6.4.4 of the SSAM submittal which demonstrates that reductions in the flow into the hot assembly, when considering both top and bottom peaked power shapes, have minimal influence on the critical LHGR.

Because NuScale demonstrated that the new modeling below the fuel pins is reasonable and because NuScale is still applying the 5 percent flow reduction, which accounts for uncertainties in the flow distribution going into the hot assembly, the NRC staff has determined that the new treatment of the inlet flow distribution is acceptable.

Inlet Temperature Distribution

The NRC staff previously reviewed and approved NuScale's methodology for calculating the inlet temperature distribution in the NSAM topical report (Reference 9). Because the methodology applied in the SSAM is the same methodology as that approved in the NSAM, the NRC staff has determined that no additional review is required for the SSAM.

3.9 Turbulent Mixing (**No Change**)

The NRC staff previously reviewed and approved NuScale's methodology for calculating turbulent mixing in the NSAM topical report (Reference 9). Because the methodology applied in the SSAM is the same methodology as that approved in the NSAM, the NRC staff has determined that no additional review is required for the SSAM.

3.10 Radial Power Distribution (**Replacement**)

The NRC staff previously reviewed and approved NuScale's methodology for the radial power distribution in the NSAM topical report (Reference 9). Like the previously approved method in the NSAM, the SSAM also makes use of a conservative radial power distribution that accounts for the worst distribution throughout the cycle, and that distribution bounds the technical specification limits on the radial peaking factor. Additionally, like the previous NSAM, the radial power distribution is held constant through the transient. Because this methodology, which is applied in the SSAM, is the same methodology as approved in the NSAM, the NRC staff has determined that no additional review is required for the SSAM.

However, additional details on the application of the radial power distribution are different in the application of the SSAM. Therefore, the NRC staff evaluated each aspect of the radial power distribution, as presented below.

3.10.1 Static Standard Review Plan Section 15.4 Analyses (**Replacement**)

The radial power distribution can change during a scenario especially if that scenario results in control rod movement. However, the SSAM calculation methodology assumes that the radial power distribution is held constant. Therefore, an augmentation factor is needed to modify the radial power distribution such that the radial power experienced over the entire scenario is the maximum radial power that would be observed during the actual scenario. However, simply increasing the radial power at one location in the hot assembly would result in increasing the overall core power. Therefore, while NuScale does increase the radial power in the hot assembly, it also lowers power in an assembly far away from the hot assembly such that there is no change in total core power. The NRC staff finds that there is reasonable assurance that using the highest radial power anticipated during a scenario's entire event progression would result in an accurate or conservative analysis for those scenarios which are analyzed using static (i.e., steady-state) methods. Therefore, the NRC staff has determined that the application of the radial peaking augmentation factor is acceptable.

3.10.2 Time-Dependent Standard Review Plan Section 15.4 Analyses (**No Change**)

The NRC staff previously reviewed and approved NuScale's methodology for calculating time-dependent safety analysis in the NSAM topical report (Reference 9). Because the methodology applied in the SSAM is the same methodology as that approved in the NSAM, the NRC staff has determined that no additional review is required for the SSAM.

3.10.3 Enthalpy Rise Hot Channel Factor (**Replacement**)

The NRC staff previously reviewed and approved NuScale's methodology for the radial power distribution in the NSAM topical report (Reference 9). However, NuScale changed the methodology used in the SSAM such that portions of the previous approval are no longer applicable, specifically the equation for the enthalpy rise hot channel factor itself, the uncertainties associated with the equation, and the allowance for the peak $F_{\Delta H}$ rod to occur in a peripheral row.

An example of the enthalpy rise hot channel factor used for safety analysis is given in equation 3-8 of the SSAM. However, NuScale has not provided a final method or value for determining the values in the equation. Such a method or value would need to be reviewed and approved prior to application of the SSAM. This is captured in condition and limitation 2. The SSAM addresses the uncertainty of the enthalpy rise hot channel factor by modeling the uncertainties of the components that make up the factor. These uncertainties are evaluated by the NRC staff in Sections 3.10.5, 3.12.2, and 3.12.4 of this SE.

In the previously reviewed and approved NSAM topical report (Reference 9), NuScale created a special confirmation to ensure that the peak $F_{\Delta H}$ rod did not occur in a peripheral row. As stated in the NSAM topical report, NuScale did this because they determined that the outer row would be influenced by direct crossflow from the annulus channel between assemblies. As this channel is not simulated in CHF testing, there is no validation correlation for predicting CHF in this channel. As stated in the NSAM topical report, to ensure that a crossflow neighboring channel remains with the test configuration, NuScale constrained its design to ensure that a peak $F_{\Delta H}$ rod did not occur in a peripheral row.

It is permissible for the peak $F_{\Delta H}$ to occur in a peripheral assembly in the actual core design because the analysis forces the peak $F_{\Delta H}$ to occur at a limiting interior location, and moving the peak to a location closer to the edge of the fuel assembly would increase crossflow from other assemblies and result in increased cooling. Because the removal of this restriction is not a change in how the core will be analyzed, as the peak $F_{\Delta H}$ will occur near the center of the limiting assembly, but is a recognition that such an analysis is reasonably bounding for actual designs which may have the peak $F_{\Delta H}$ occurring at other locations within the assembly, NRC staff has determined that the removal of the restriction on the peak $F_{\Delta H}$ for actual core designs is acceptable.

3.10.4 Radial Flux Tilt (**No Change**)

The NRC staff previously reviewed and approved NuScale's methodology for calculating radial flux tilt in the NSAM topical report (Reference 9). Because the methodology applied in the SSAM is the same methodology as that approved in the NSAM, the NRC staff has determined that no additional review is required for the SSAM.

3.10.5 All Rods Out Power Dependent Insertion Limit Enthalpy Rise Hot Channel Factor (**Replacement**)

The All Rods Out Power Dependent Insertion Limit Enthalpy Rise Hot Channel Factor was used by NuScale to address changes in power over the entire transient, as only a single power level is used during the computational analysis of the transient. For the SSAM, NuScale chose to modify this method and applied the augmentation factor described in Section 3.10.1. The NRC staff has determined that no additional review is required because this section is no longer applicable to the SSAM and has been replaced with the information in Section 3.10.1.

3.10.6 Determining the Bounding Radial Power Distribution (**Replacement**)

In Section 6.4.2 of the NSAM topical report (Reference 9), NuScale provided a sensitivity study which confirmed that the radial power distribution far from the hot channel has negligible impact on the MCHFR results. NuScale used this study to justify the assumption that the use of a radial power distribution with the hot rod at the design peaking limit would be sufficient to bound any distribution in a cycle-specific core. Because the same assumption is applied in the SSAM as was approved in the NSAM, the NRC staff has determined that no additional review is required for the SSAM for this assumption.

The goal of the bounding radial power distribution is to result in a limiting value of MCHFR in the hot rod and subchannel, and not to represent the actual radial power in the core during a transient. To this end, NuScale considers a “flat” power distribution as a conservatism, as this distribution will limit the amount of turbulent mixing and diversion crossflow in the hot subchannel, resulting in a more limiting prediction of MCHFR. Because the same assumption is applied in the SSAM as approved in the NSAM, the NRC staff has determined that no additional review is required for the SSAM for this assumption.

In evaluating a core design, NuScale determines which assemblies could be limiting by considering the assembly peaking (i.e., the average power of the assembly compared to the average power of the average assembly in the core), and the rod peaking in the assembly. For an assembly to be close to limiting, the assembly peaking must be high, or else the power in the hot rod would not be sufficient to result in limiting behavior. Additionally, assemblies with high peaking of individual rods are not limiting because of the enhanced crossflow which enables these assemblies to have better internal heat transfer. Thus, the limiting assemblies must have flat peak-to-average ratios for the rods in the assembly and must occur at high assembly peaking values.

NuScale's process for determining the limiting radial power distribution which will be used for the safety analysis relies on **{{**

}}. The NRC staff finds that NuScale's process for determining the bounding radial power distribution would result in a radial power distribution which could reasonably be expected to be a bounding distribution for core designs; therefore, the NRC staff has determined that the generation of the bounding radial power distribution is acceptable.

3.10.7 <u>Deterministic Radial Power Distribution (**Replacement**)</u>

While this section was needed for the NSAM topical report (Reference 9), because of the different treatment of uncertainties in the SSAM submittal, this section in no longer needed. Uncertainties of the radial power distribution are discussed in Section 3.12.

3.10.8 <u>Axial Power Distribution (**No Change**)</u>

The NRC staff previously reviewed and approved NuScale's methodology for calculating the axial power distribution in the NSAM topical report (Reference 9). Because the methodology applied in the SSAM is the same methodology as that approved in the NSAM, the NRC staff has determined that no additional review is required for the SSAM.

3.10.9 <u>Standard Review Plan Section 15.4 Analyses (**No Change**)</u>

The NRC staff previously reviewed and approved NuScale's methodology for calculating the limiting axial power shape in the NSAM topical report (Reference 9). Because the methodology applied in the SSAM is the same methodology as that approved in the NSAM, the NRC staff has determined that no additional review is required for the SSAM.

3.11 <u>Numerical Solution (**No Change**)</u>

The NRC staff previously reviewed and approved NuScale's methodology for calculating the numerical solution in the NSAM topical report (Reference 9). Because the methodology applied in the SSAM is the same methodology as that approved in the NSAM, the NRC staff has determined that no additional review is required for the SSAM.

3.12 <u>Statistical Method and Treatment of Uncertainties (**Replacement**)</u>

In its uncertainty quantification (UQ) analysis, NuScale determined the appropriate probability distribution based on certain factors and applied that distribution to the value of specific variables. In general, the NRC staff finds that assuming that measurements are normally disturbed is reasonable, and that applying a uniform distribution when the probabilities of a bounded distribution are unknown can be acceptable. However, the staff is unaware of any approach that could be used to determine conservative distributions and, therefore, reviewed the uncertainty models chosen, including the probability distributions chosen, based on if those distributions accurately or conservatively capture the uncertainty in their corresponding parameters in the subsections below.

3.12.1 Uncertainty in Analysis Method (**Replacement**)

The following uncertainties are focused on the analysis method itself.

3.12.1.1 Computer Code Uncertainty (**Replacement**)

The computer code uncertainty is a general uncertainty applied to a computer code that was meant to capture uncertainties due to the fidelity of the computational models in predicting the physics as well as uncertainties due to the change of the continuous equations of physics into discretized equations and the resulting sensitivities to radial and axial nodalization. Instead of considering a single code, NuScale has followed the general practice of separating the overall uncertainty into two independent uncertainties.

The uncertainties associated with the computational model's ability to correctly predict physics are quantified through comparison to experimental data, in particular, quantified through comparison to CHF data (as discussed in Section 3.12.1.2). Historically, these physics-based uncertainties have dominated the overall uncertainty. In scientific modeling and simulation, evaluating these uncertainties is commonly called validation.

The uncertainties associated with using discretized equations instead of continuous equations (e.g., impacts of mesh) are not quantified directly, but instead are treated by ensuring that the mesh size used is reasonable. As these uncertainties have historically been smaller, this practice has been considered acceptable for CHF analysis. In scientific modeling and simulation, evaluating these uncertainties is commonly called verification.

Given the direct treatment of physics-based uncertainties and the use of mesh sensitivities to ensure that the axial and radial nodalization adequately resolves the solution, the NRC staff has determined that the computer code uncertainty has been adequately quantified.

3.12.1.2 Critical Heat Flux Correlation Uncertainty (**Replacement**)

The CHF correlation uncertainty is quantified as the variability in the correlation's predicted accuracy of the CHF test data. The measured-to-predicted values from CHF testing are assumed to be a representative sample from the population of all possible measured-to-predicted values and, therefore, that sample can provide useful information for any future UQ analysis, such as using the variance from the sample as an estimate of the variance of the underlying population or using the distribution of the sample as an estimate of the distribution of the underlying population.

However, as noted by NuScale, the main figure of merit for the CHF validation is the 95/95. The 95/95 is an estimate of the 95th percentile of the validation population using a method that has a 95 percent confidence level. And while the 95/95 of the sample will not change without additional data, because this value is used as an analytical limit, it is common for that limit to be increased to account for other uncertainties. Thus, NuScale has committed to adjusting the sample of measured-to-predicted data in any UQ analysis such that the 95/95 of the adjusted sample matches the approved limit for the given CHF correlation. Because the measured-to-predicted values represent the uncertainty in the CHF correlation and their distribution would be adjusted to ensure that the adjusted distribution maintains the approved design limit, the NRC staff has determined that CHF correlation uncertainty has been adequately quantified.

3.12.2 Uncertainty in Operating Conditions (**Replacement**)

The following uncertainties are focused on the plant operating conditions which are the boundary conditions of the computational model.

3.12.2.1 Core Thermal Power (**Replacement**)

Equation 3-12 in the SSAM provides the basic formula for evaluating the core thermal power. However, NuScale has not provided a final method or value for determining the values in this equation. Such a method or value would need to be reviewed and approved prior to application of the SSAM. This is captured in condition and limitation 2.

3.12.2.2 Core Inlet Flow (**Replacement**)

Equation 3-13 in the SSAM provides the basic formula for evaluating the core inlet flow. However, NuScale has not provided a final method or value for determining the values in the equation. Such a method or value would need to be reviewed and approved prior to application of the SSAM. This is captured in condition and limitation 2.

3.12.2.3 Core Inlet Temperature (**Replacement**)

Equation 3-14 in the SSAM provides the basic formula for evaluating the core inlet temperature. However, NuScale has not provided a final method or value for determining the values in the equation. Such a method or value would need to be reviewed and approved prior to application of the SSAM. This is captured in condition and limitation 2.

3.12.2.4 Core Exit Pressure (**Replacement**)

Equation 3-15 in the SSAM provides the basic formula for evaluating the core exit pressure. However, NuScale has not provided a final method or value for determining the values in the equation. Such a method or value would need to be reviewed and approved prior to application of the SSAM. This is captured in condition and limitation 2.

3.12.2.5 Enthalpy Rise Measurement Uncertainty (**Replacement**)

This section discusses the enthalpy rise measurement uncertainty. However, NuScale has not provided a final method or value for determining this value. Such a method or value would need to be reviewed and approved prior to application of the SSAM. This is captured in condition and limitation 2.

3.12.3 Uncertainty in Physical Data Inputs (**Replacement**)

The following uncertainties (Section 3.12.4 – Section 3.12.10) are focused on the physical data inputs used in the VIPRE model.

3.12.4 Enthalpy Rise Engineering Uncertainty (**Replacement**)

This section discusses the enthalpy rise engineering uncertainties. However, NuScale has not provided a final method or value for determining these values. Such a method or value would need to be reviewed and approved prior to application of the SSAM. This is captured in condition and limitation 2.

3.12.5 Heat Flux Engineering Uncertainty (**Replacement**)

Equation 3-16 in the SSAM provides the basic formula for evaluating the heat flux engineering uncertainty. However, NuScale has not provided a final method or value for determining the values in the equation. Such a method or value would need to be reviewed and approved prior to application of the SSAM. This is captured in condition and limitation 2.

3.12.6 Linear Heat Generation Rate Engineering Uncertainty (**Replacement**)

The NRC staff previously reviewed and approved NuScale's methodology for calculating the linear heat generation rate uncertainty in the NSAM topical report (Reference 9). Because the methodology applied in the SSAM is the same methodology as that approved in the NSAM, and because this uncertainty is not related to CHF but used in ensuring the preclusion of fuel melt, the NRC staff has determined that no additional review is required for the SSAM.

3.12.7 Radial Power Distribution (SIMULATE5) Uncertainty (**Replacement**)

NuScale determined that any uncertainty in the neutronic computer code which is used to calculate the radial power distribution has been accounted for by biasing the radial peaking limit in the hot rod and in the hot subchannel and having these at the radial peaking analysis limit. Previous sensitivity studies have shown that the rod powers a few rows away from the hot subchannel have a negligible impact on the MCHFR, thus, having the hot subchannel be at the limiting radial powers would result in the limiting condition. The NRC staff previously reviewed and approved this reasoning in the NSAM topical report (Reference 9). Because the assumption applied in the SSAM is the same assumption as that approved in the NSAM, the NRC staff has determined that no additional review is required for the SSAM.

3.12.8 Fuel Rod and Assembly Bow Uncertainty (**Replacement**)

The following two uncertainties are focused on fuel rod bow and assembly bow.

3.12.8.1 Fuel Rod Bow Uncertainty (**Replacement**)

Equation 3-17 in the SSAM provides the basic formula for evaluating the fuel rod bow uncertainty. However, NuScale has not provided a final method or value for determining the values in the equation. Such a method or value would need to be reviewed and approved prior to application of the SSAM. This is captured in condition and limitation 2.

3.12.8.2 Assembly Bow Uncertainty (**Replacement**)

The NRC staff previously reviewed and approved NuScale's methodology for assessing assembly bow penalty and that it was not needed in the NSAM topical report (Reference 9). Because the methodology applied in the SSAM is the same methodology as that approved in the NSAM, the NRC staff has determined that no additional review is required for the SSAM.

3.12.9 Core Inlet Flow Distribution Uncertainty (**Replacement**)

While the location of core inlet flow has been changed from that in the NSAM topical report due to the change in modeling of the core, the NRC staff has determined that this change would not impact the modeling of the core inlet flow distribution uncertainty. Because the methodology applied in the SSAM is the same methodology as that approved in the NSAM, the NRC staff has determined that no additional review is required for the SSAM.

3.12.10 Core Exit Pressure Distribution Uncertainty (**Replacement**)

While the location of core exit pressure has been changed from that in the NSAM topical report due to the change in modeling of the core, the NRC staff has determined that this change would not impact the modeling of the core exit pressure distribution uncertainty. Because the methodology applied in the SSAM is the same methodology as that approved in the NSAM, the NRC staff has determined that no additional review is required for the SSAM.

3.13 Bias and Uncertainty Application within Analysis Methodology (**Replacement**)

The following sections summarize NuScale's treatment of biases and random uncertainties.

3.13.1 Statistical Methods (**Replacement**)

The following subsections contain general information on statistical methods that NuScale is applying in the SSAM. Because the information discussed in each subsection is general statistical information, the NRC staff has determined that no review is required.

3.13.1.1 Uniform Distribution (**Replacement**)

In this section, NuScale provides the general definition of a uniform distribution. Because this information is general statistical information, the NRC staff has determined that no review is required.

3.13.1.2 Normal Distribution (**Replacement**)

In this section, NuScale provides a discussion of the Box-Mueller transformation, a method used to generate pairs of normally distributed random numbers from pairs of uniformly distributed random numbers. Because this information is general statistical information, the NRC staff has determined that no review is required.

3.13.1.4 Quality Assurance Sampling (**Replacement**)

In this section, NuScale provides a discussion of determining estimates of the 95/95 level of population using a non-deterministic method. Because this information is general statistical information, the NRC staff has determined that no review is required.

3.13.2 Statistical CHF Analysis Limit (**Replacement**)

The statistical CHF analysis limit (SCHFAL) is the random variable used by NuScale to quantify the uncertainties that occur in the MCHFR value. This variable is calculated by combining the uncertainties in:

- the CHF correlation's predictive capability (i.e., the values of the correlation's prediction of validation data compared to the measured values) (Section 3.12.1.2)
- the fuel rod bow penalty (Section 3.12.8.1)
- the heat flux engineering uncertainty (Section 3.12.5)
- the impact of uncertainties in the MCHFR value at the state point at which the MCHFR is calculated (Section 3.13.3)

These uncertainties are combined using equation 3-24 in the SSAM in a Monte Carlo methodology. In this equation, fuel rod bow is treated as a penalty in that it always increases the SCHFAL, while the other terms are treated as variabilities as they can both increase and decrease the SCHFAL value.

The Monte Carlo sampling process is performed a specified number of times to ensure that a non-deterministic 95/95 value can be calculated. This value is the 95/95 limit. The details about its calculation are discussed in the subsections below.

3.13.2.1 Best-Estimate Model Reference State-Point (**Replacement**)

The Monte Carlo sampling procedure used by NuScale attempts to determine the uncertainty in the CHFR value over a space of values. To this end, it combines the two common Monte Carlo analysis types: (1) spatial sampling – sampling values over some defined space to determine the possible values of a variable and (2) probabilistic sampling – combining values from multiple random variables to generate a sample of a new random variable. While Monte Carlo is used to perform both types of analysis, the two analyses produce different results. In spatial sampling, the results of the analysis represent the possible values of the given variable. In probabilistic sampling, the results of the analysis represent a sample of a random variable which can be assumed to be a representative sample from the population for that random variable. While statistics from the output of probabilistic sampling are estimates of the parameters of the underlying population, statistics from the output of spatial sampling have no such meaning.

Combining both types of analysis into a single Monte Carlo analysis is possible if it can be shown that the spatial variation in the variable's value does not dramatically change over the space being considered. To demonstrate this, NuScale performed a sensitivity evaluation in which it compared a **{{**

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While NuScale's analysis does not conclusively prove that the results from spatial sampling can be used to generate bounding statistics, the NRC staff has determined that the analysis does use the best available methods and that the study provides reasonable evidence that the Monte Carlo sampling process is not impacted by the location of the state point (i.e., it is independent of the location in the application domain).

By demonstrating that its Monte Carlo sampling process is not impacted by the state point location, the NRC staff concludes that NuScale has demonstrated that the sampling process results in a representative sample of the underlying population of the CHFR values and, therefore, that the 95/95 is a reasonable estimate of the true 95^{th} percentile from that population.

In this process, it is expected that the code may not converge on some very small percentage of runs. Based on Section 3.13.2 of the SSAM, it is the NRC staff's understanding that NuScale will investigate any such non-convergences and ensure that their occurrence is reasonable and thus that run should be ignored in the analysis (e.g., the state point that had been randomly chosen for the run is a non-physical state point and was randomly chosen due to the mathematically simplistic description of the application domain). Any non-convergence at a point at which the code would have been expected to result in convergence is an indication of a potential bug in the code.

3.13.3 ΔMCHFR Calculation Process (**Replacement**)

In order to determine the impact of uncertainties, NuScale is **{{**

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}}. Therefore, the NRC staff concludes that the calculation and application of the ∆MCHFR value is acceptable for quantifying uncertainties of the variables which are used to generate the ∆MCHFR value.

3.13.4 Calculating the Statistical CHF Analysis Limit (**Replacement**)

Because NuScale uses well accepted non-parametric methods for determining the SCHFAL and uses those methods in a reasonable manner such that the SCHFAL will be accurately or conservatively predicted, the NRC staff concludes that the calculation of the SCHFAL is acceptable.

3.13.5 Summary of Bias and Uncertainty Treatment (**Replacement**)

This section of the SSAM submittal provides a table that summarizes the various uncertainties discussed in Section 3. Because this section is only a summary, the NRC staff has determined that no additional review is required as the regulatory evaluation of each uncertainty is discussed in the section of the SE associated with the specific uncertainty.

3.14 Mixed Core Analysis (**No Change**)

The NRC staff previously reviewed and approved NuScale’s methodology for performing mixed core analysis in the NSAM topical report (Reference 9). Because the methodology applied in the SSAM is the same methodology as that approved in the NSAM, the NRC staff has determined that no additional review is required for the SSAM.

3.15 Methodology-Specific Acceptance Criteria (**Supplement**)

The NRC staff previously reviewed and approved NuScale’s determination of methodology acceptance criteria in the NSAM topical report (Reference 9). Because the process of determination remains unchanged in the SSAM as was approved in the NSAM with one exception, the NRC staff has determined that no additional review is required for the SSAM for everything except the exception. The exception is related to NuScale’s allowance for the MCHFR to occur in a peripheral subchannel and this is addressed in Section 3.10.3.1.

4.0 Transient-Specific Applications Methodologies (**No Change**)

The NRC staff previously reviewed and approved NuScale's methodology for transient-specific applications in the NSAM topical report (Reference 9). Because the methodology applied in the SSAM is the same methodology as that approved in the NSAM, the NRC staff has determined that no additional review is required for the SSAM. Further, the SSAM methodology only impacts the CHF limit to which the results of each transient would be compared and does not generally impact how each transient would be performed.

5.0 VIPRE-01 Qualification (**No Change**)

The NRC staff previously reviewed and approved NuScale's VIPRE-01 qualification in the NSAM topical report (Reference 9). Because the qualification applied in the SSAM is the same qualification as that approved in the NSAM, the NRC staff has determined that no additional review is required for the SSAM.

6.0 Example Calculation Results (**Supplement**)

In general, the example calculation results in the NSAM are applicable to the SSAM. However, due to specific differences in nodalization, some changes were needed. Therefore, each subsection is addressed below.

6.1 General Inputs (**N/A**)

Section 6.1 provides an example calculation using the NSAM and does not describe any of the SSAM methodology. Further, the example is not an example calculation of the SSAM, hence it is categorized by the NRC staff as N/A as it does not have a direct impact on the approval of the SSAM. However, the example may still be useful in understanding the SSAM.

6.2 Steady-State Case (**N/A**)

Section 6.2 provides an example calculation using the NSAM and does not describe any of the SSAM methodology. Further, the example is not an example calculation of the SSAM, hence it is categorized by the NRC staff as N/A as it does not have a direct impact on the approval of the SSAM. However, the example may still be useful in understanding the SSAM.

6.3 Transient Cases (**No Change**)

The NRC staff previously reviewed and approved the transient case in the NSAM topical report (Reference 9). Because the transient case applied in the SSAM is the same as that approved in the NSAM, the NRC staff has determined that no additional review is required for the SSAM.

6.4 Sensitivity Analysis (**Supplement**)

The various aspects of the sensitivity analysis are addressed in the subsections below.

6.4.1 Radial Geometry Nodalization (**Replacement**)

In this analysis, NuScale performed a sensitivity of the radial nodalization using the **{{**

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6.4.2 Radial Power Distribution (**No Change**)

The NRC staff previously examined the sensitivity study for the radial power distribution in the NSAM topical report (Reference 9). Because of the similarities between the NSAM and SSAM approaches, the NRC staff finds that the results of that study would be applicable to the SSAM and, therefore, the NRC staff has determined that no additional review is required for the SSAM.

6.4.3 Axial Geometry Nodalization (**Replacement**)

This analysis is evaluated in Section 3.7 of this SE.

6.4.4 Inlet Flow Distribution (**No Change**)

The NRC staff previously examined the sensitivity study for the inlet flow distribution in the NSAM topical report (Reference 9). However, in those sensitivities, the NRC staff noted that **{{**

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Because of the similarities between the NSAM and SSAM approaches, the NRC staff finds that the results of that study would be applicable to the SSAM, and because of the sensitivity which demonstrated that large conservative changes to the inlet flow distribution resulted in a minimal impact to the critical LHGR, the NRC staff has determined that this sensitivity analysis demonstrates the minimal impact of flow maldistribution on MCHFR.

6.4.5 Turbulent Mixing Parameter (**No Change**)

The NRC staff previously examined the sensitivity study for the turbulent mixing parameter in the NSAM topical report (Reference 9). Because of the similarities between the NSAM and SSAM approaches, the NRC staff finds that the results of that study would be applicable to the SSAM and, therefore, the NRC staff has determined that no additional review is required for the SSAM.

6.4.6 <u>Turbulent Momentum Parameter (**No Change**)</u>

The NRC staff previously examined the sensitivity study for the turbulent momentum parameter in the NSAM topical report (Reference 9). Because of the similarities between the NSAM and SSAM approaches, the NRC staff finds that the results of that study would be applicable to the SSAM and, therefore, the NRC staff has determined that no additional review is required for the SSAM.

6.4.7 <u>Grid Loss Coefficient (**No Change**)</u>

The NRC staff previously examined the sensitivity study for grid loss coefficients in the NSAM topical report (Reference 9). Because of the similarities between the NSAM and SSAM approaches, the NRC staff finds that the results of that study would be applicable to the SSAM and, therefore, the NRC staff has determined that no additional review is required for the SSAM.

6.4.8 <u>Numerical Solution Parameters (**No Change**)</u>

The NRC staff previously examined the sensitivity study for the numerical solution parameters in the NSAM topical report (Reference 9). Because of the similarities between the NSAM and SSAM approaches, the NRC staff finds that the results of that study would be applicable to the SSAM and, therefore, the NRC staff has determined that no additional review is required for the SSAM.

6.5 <u>General Input Sensitivity Analysis (**No Change**)</u>

The NRC staff previously examined the general input sensitivity analysis in the NSAM topical report (Reference 9). Because of the similarities between the NSAM and SSAM approaches, the NRC staff finds that the results of that analysis would be applicable to the SSAM and, therefore, the NRC staff has determined that no additional review is required for the SSAM.

7.0 <u>Summary and Conclusions (**Supplement**)</u>

The following section details the summary and conclusions of the SSAM.

7.1 <u>VIPRE-01 Safety Evaluation Report Requirements (**No Change**)</u>

The NRC staff previously examined the VIPRE-01 safety evaluation report requirements in the NSAM topical report (Reference 9). Because of the similarities between the NSAM and SSAM approaches, the NRC staff finds that the satisfying of those requirements would be applicable to the SSAM and, therefore, the NRC staff has determined that no additional review is required for the SSAM.

7.2 <u>Criteria for Establishing Applicability of Methodology (**Replacement**)</u>

The criteria for establishing the applicability of the methodology are given below. The criteria for establishing the applicability of the methodology section of the SSAM are generally similar to the NSAM and represent the criteria that need to be satisfied at a minimum for the SSAM to be applicable. Changes or deviations from the evaluation model described in the NSAM and/or SSAM would require additional NRC staff review and approval.

7.2.1 General Criteria (**Replacement**)

The NRC staff previously examined the general criteria for establishing the applicability of the methodology in the NSAM topical report (Reference 9). However, in the SSAM, NuScale has removed the following requirements:

- The MCHFR must occur in a channel geometry for which there is a valid CHF correlation (a unit or guide tube or instrument tube cell).
- The MCHFR must not occur on a peripheral subchannel of an assembly when using the fully detailed one-eighth core model.
- The hot channel must occur adjacent to the hot rod.

As discussed in Section 3.10.3 above, the removal of these requirements is for actual core designs, which is acceptable because the simulated core used in the SSAM will bound the actual core, as the MCHFR will be forced to occur in the middle of the assembly resulting in a bounding statistical analysis. Because NuScale's general criteria will result in an accurate or conservative application of the methodology, the NRC staff has determined that the general criteria are acceptable.

7.2.2 Critical Heat Flux Correlation (**Replacement**)

The NRC staff previously examined the CHF correlation criteria for establishing the applicability of the methodology in the NSAM topical report (Reference 9). While NuScale has made some editorial changes to these criteria, the NRC staff finds that the criteria stated in the SSAM are substantively the same as those criteria approved in the NSAM and, therefore, the NRC staff has determined that the CHF correlation criteria are acceptable. See SE Section 3.3 for additional information.

7.2.3 Nuclear Analysis Discipline Interface (**Replacement**)

Because NuScale will confirm that the bounding analysis limits for each cycle are used in its analysis, the NRC staff has determined that the nuclear analysis discipline interface is acceptable.

7.2.4 Transient Discipline Interface (**Replacement)**

The NRC staff previously examined the transient discipline interface criteria in the NSAM topical report (Reference 9). While NuScale has made some editorial changes to these criteria, the NRC staff finds that the criteria stated in the SSAM are substantively the same as those criteria approved in the NSAM and, therefore, the NRC staff has determined that the transient discipline interface criteria are acceptable.

7.3 Cycle-Specific Confirmations (**Replacement**)

The NRC staff previously examined the cycle-specific confirmations criteria in the NSAM topical report (Reference 9). While NuScale has made some changes to these criteria, the NRC staff finds that the criteria stated in the SSAM are substantively the same as those criteria approved in the NSAM with one exception and, therefore, the NRC staff has determined that they are acceptable. The exception is the removal of the requirement for the hot rod to not be on the assembly periphery and it is addressed above in Section 3.10.3.

7.4 Key Fuel Design Interface Requirements (**Replacement**)

The NRC staff previously examined the key fuel design interface requirements in the NSAM topical report (Reference 9). Because of the similarities between the NSAM and SSAM approaches, the NRC staff finds that the satisfying of those requirements would be applicable to the SSAM and, therefore, the NRC staff has determined that no additional review is required for the SSAM.

7.5 Unique Features of the NuScale Design (**Supplement**)

The NRC staff previously examined the unique features of the NuScale design in the NSAM topical report (Reference 9). NuScale has updated this table consistent with the requested power uprate for its reactor. Because this table reflects the current design, the NRC staff has determined that no additional review is required for the SSAM.

8.0 References (**Supplement**)

Because this section contains the appropriate references for the documents cited in the SSAM submittal (Reference 13), the NRC staff has determined that no additional review is required for the SSAM.

4.0 CONDITIONS AND LIMITATIONS

The following condition and limitation is provided in Section 5.0 of the NRC staff's SE for the approval of the NSAM (Reference 10). Because the SSAM is based on the approved NSAM, this same condition and limitation is applicable to the SSAM. The condition and limitation is reproduced below as condition and limitation 1 for convenience, with slight wording changes for clarity.

1. An applicant referencing [the SSAM] in the safety analysis must also reference an approved CHF correlation which has been demonstrated to be applicable for use with [the NSAM]. The basis for this Condition is provided in Section 4.1 of the [SE for the NSAM].

Based on the above evaluation, the following condition and limitation 2 is applicable specifically to the SSAM.

2. The SSAM relies on multiple submodels to calculate the statistical critical heat flux analysis limit. While some of these submodels have been reviewed and approved as part of the NRC staff's review and approval of the SSAM, the submodels listed below would need to be reviewed and approved before the application of this methodology for a licensing analysis. That review and approval may consist of approval of specific values for variables, approval of the model used for the variables, and/or approval of the method by which the model will be generated for those variables. Additionally, while the numerical inputs to the submodel must also be approved, it is often sufficient to ensure that the values are obtained from a trusted source. The submodels that require such NRC staff review and approval before application of the SSAM are:

    a. The maximum hot rod radial peaking analysis limit, including measurement uncertainties. An example of this is given in equation 3-8 of the SSAM.

    b. The models and values used to determine the core thermal power. This is given in equation 3-12 of the SSAM.

    c. The models and values used to determine the core inlet flow. This is given in equation 3-13 of the SSAM.

    d. The models and values used to determine the core inlet temperature. This is given in equation 3-14 of the SSAM.

    e. The models and values used to determine the core exit pressure. This is given in equation 3-15 of the SSAM.

    f. The models and values used to determine the enthalpy rise measurement uncertainty.

    g. The models and values used to determine the enthalpy rise engineering uncertainties.

    h. The models and values used to determine the heat flux engineering uncertainty. This is given in equation 3-16 of the SSAM.

    i. The models and values used to determine the fuel rod bow uncertainty. This is given in equation 3-17 of the SSAM.

5.0 CONCLUSIONS

The NRC staff reviewed the modifications to the original subchannel methodology, the NSAM (Reference 9), which resulted in the creation of the statistical subchannel methodology, the SSAM. The NRC staff's review of each of the sections of the SSAM is summarized in Section 3 of this SE. As part of this review, the NRC staff determined that either no additional review was required for the SSAM due to the similarity with the NSAM or that the change to the NSAM (either supplementation or replacement) to create the SSAM was acceptable. The NRC staff also determined that two conditions and limitations, specified in Section 4 of the SE, are applicable to the SSAM.

Given the acceptability of each of the individual sections of the SSAM and the previous acceptability of the NSAM on which the SSAM is based, the NRC staff finds that the SSAM as defined in Reference 13 and in this SE is an acceptable methodology to calculate the margin to fuel thermal limits such as the critical heat flux ratio through a statistical combination of the uncertainties, provided that the conditions and limitations have been satisfied.

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3. Email from Bavol, B.M., NRC, to Norris, R., NuScale, "Completeness determination for NuScale Topical Report, TR-108601, Revision 0, 'Statistical Subchannel Analysis Methodology,'" dated February 28, 2022 (ML22053A142).

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11. NuScale, “Statistical Subchannel Analysis Methodology, Supplement 1 to TR-0915-17564-P-A, Revision 2, Subchannel Analysis Methodology,” TR-108601-P, Revision 3, dated October 12, 2023 (ML23285A342 (Proprietary Version, Non-Publicly Available) and ML23285A341 (Nonproprietary Version, Publicly Available)).

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Section B

Licensing Topical Report

Statistical Subchannel Analysis Methodology

Supplement 1 to TR-0915-17564-P-A, Revision 2, Subchannel Analysis Methodology

March 2024

Revision 4

Docket: 52-050

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Licensing Topical Report

Department of Energy Acknowledgement and Disclaimer

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List of Affected Pages

Revision Number	Page Number	Explanation
0	All	Initial Issue
1	All	Reissued to address NRC Request for Supplemental Information (RSI)
2	All	Reissued to reintroduce modeling removed in Revision 1 with additional supporting justification as discussed during NRC audit.
3	All	Incorporated changes in response to NRC audit questions.

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Abstract

This report documents the NuScale statistical subchannel analysis methodology using the VIPRE-01 computer code. This methodology is used to calculate margin to fuel thermal limits, such as critical heat flux ratio and fuel centerline temperature.

This report discusses how NuScale meets the NRC requirements for use of VIPRE-01, the modeling methodology for performing steady-state and transient subchannel analyses, and the qualification of the code for application to the NuScale design. NuScale intends to use this methodology for thermal-hydraulic analysis in support of future design work for NuScale reactors.

NuScale requests NRC approval to utilize this methodology, with the noted limitations described herein, for the NuScale thermal-hydraulic design and supporting analysis.

Executive Summary

The purpose of this topical report supplement is to define and justify a statistical based methodology for steady-state and transient subchannel analysis applications. The bases for how the subchannel model is developed and utilized, as well as its application is discussed.

This methodology will be utilized to evaluate thermal margin and demonstrate adequate heat removal capability in design applications of the NuScale Power Module (NPM). NuScale requests NRC review and approval of the statistical treatment of uncertainties presented in this supplement.

The specific element of the requested approval is:

- The methodology for treatment of uncertainties in the NuScale statistical subchannel methodology

1.0 Introduction

1.1 Purpose

The purpose of this topical report supplement is to define and justify a statistical based methodology for steady-state and transient subchannel analysis applications. This methodology will be utilized to evaluate thermal margin and demonstrate adequate heat removal capability in design applications of the NuScale Power Module (NPM). NuScale requests NRC review and approval of the statistical treatment of uncertainties presented in this supplement to the Subchannel Analysis Methodology topical report TR-0915-17564-P-A, Revision 2 (Reference 8.1.1).

The specific element of the requested approval is:

- The treatment of uncertainties in the NuScale statistical subchannel methodology.

1.2 Scope

This report describes the assumptions, codes, and methodology utilized to perform steady-state and transient subchannel analysis for design-basis accidents. This topical report focuses on the NuScale statistical subchannel methodology and is not intended to provide final detailed reactor core design or final values of any other associated accident evaluations.

1.3 Abbreviations and Definitions

Table 1-1 Abbreviations

Term	Definition
A/Q	assurance-to-quality
CDF	cumulative distribution function
LHGR	linear heat generation rate
M/P	measured-to-predicted
NPM	NuScale Power Module
SCHFAL	statistical critical heat flux analysis limit
WRS	Wilcoxon Rank Sum

1.4 Topical Report Supplement Format and Layout

This topical report supplement provides an alternative methodology compared to Reference 8.1.1. The layout of this supplement follows the layout of the original topical report in Reference 8.1.1. Section titles and content are analogous to that presented in the base topical report, unless new content is provided, and then the new content is labeled with the next available section or subsection numbering. Figures, tables, and equations are numbered such that they use the corresponding figure, table, or equation number in Reference 8.1.1. Figures, tables, and equations that are new, in that there was not analogous content in Reference 8.1.1, are provided the next sequential number in that section, to avoid confusion with the table, figure, and equation numbering in Reference 8.1.1.

2.0 Background

This section is unchanged relative to the corresponding section of Reference 8.1.1. The CHF correlations approved for use in VIPRE-01 are documented in Reference 8.1.2 and Reference 8.1.3.

2.1 VIPRE-01

This section is unchanged relative to the corresponding section of Reference 8.1.1.

2.2 As-Approved Use

This section is unchanged relative to the corresponding section of Reference 8.1.1. The CHF correlations approved for use in VIPRE-01 are documented in Reference 8.1.2. Additionally, an extension of the range of applicability for the NSP4 CHF correlation has been submitted to the NRC for approval in Reference 8.1.3. Additional NRC approved CHF correlations may be used with the code in the future.

2.3 VIPRE-01 Safety Evaluation Report Requirements

NuScale continues to fulfill the requirements of the VIPRE-01 Safety Evaluation Report requirements as detailed in the corresponding section of Reference 8.1.1.

2.4 Regulatory Requirements

This section is unchanged relative to the corresponding section of Reference 8.1.1.

3.0 General Application Methodology

This section describes an overview of the statistical thermal design analysis methodology used for NuScale subchannel analysis. The bases for how the subchannel model is developed and utilized, as well as its application, is discussed. The core is modeled with a one-pass approach, meaning all the characteristics of the hot channel are captured, including inter-channel feedback. The one-pass approach allows the use of a fully-detailed model as well as lumped channel models to resolve the desired enthalpy and flow field. The uncertainty parameters included in the statistical method are independent and do not influence the other statistically treated parameters.

3.1 Nuclear Safety Engineering Disciplines

This section is unchanged relative to the corresponding section of Reference 8.1.1.

3.2 Core Design Limits

Section 3.7 provides details regarding changes to the basemodel relative to Reference 8.1.1.

3.3 Critical Heat Flux Correlation

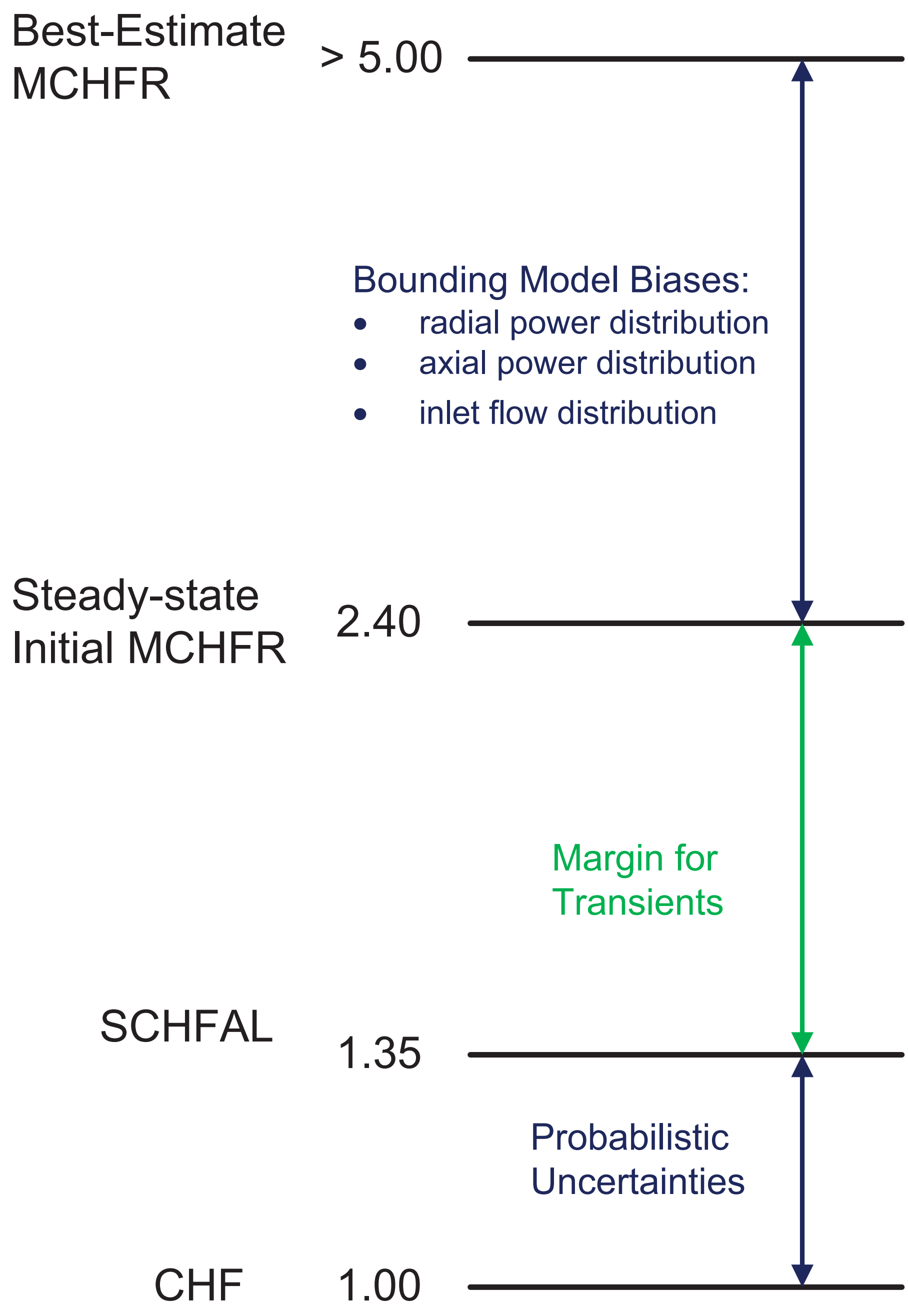
An NRC-approved CHF correlation is required for reporting thermal margin with the subchannel analysis methodology. The 5 conditions listed in Section 3.3 of Reference 8.1.1 remain applicable to the statistical subchannel analysis methodology. The NRC-approved subchannel analysis methodology LTR has an SER condition that any safety analysis referencing it is subject to referencing an approved CHF correlation. In review of the SER limitations of Reference 8.1.2, analyses using the NSP2 and NSP4 CHF correlations must be performed in accordance with Reference 8.1.1. Section 3.3.5.1 of the SER indicates the basis for the limitation is that the same computer code and models used in the data reduction are used when applying the CHF correlation. The CHF correlation performance, uncertainty, and 95/95 safety limit are dependent upon the local conditions simulated at the CHF location. Thus, the consistent use of the same computer code, same two-phase flow and heat transfer models, and same mixing model coefficients ensures the subchannel analysis methodology evaluates reactor core local conditions with the same underlying basis.

The statistical subchannel analysis methodology continues to use the same two-phase flow and heat transfer models and correlations as those used in the NRC-approved methodology of Reference 8.1.1, Section 5.6. These models remain consistent with those listed in Tables 3-14 and 3-15 in Section 3.3.1 of Reference 8.1.2. Therefore, the statistical subchannel analysis methodology is applicable with the NRC-approved NSP4 correlation in Reference 8.1.2. However, in similar fashion to the NRC-approved subchannel analysis methodology, the statistical subchannel analysis methodology is not dependent upon a specific CHF correlation as long as the 5 conditions listed in Section 3.3 of Reference 8.1.1 are satisfied.

3.4 Thermal Margin Results Reporting

The corresponding section of Reference 8.1.1 is updated to provide additional clarification for the penalty fractions in Equation 3-4 of Reference 8.1.1. These penalty fractions may be determined either deterministically or statistically to calculate the CHF analysis limit. Additionally, Figure 3-2 shows the MCHFR limits and the example margins in the MCHFR calculation in the statistical subchannel analysis methodology.

Figure 3-2 Example Thermal Margin Pictorial



3.5 Geometry Design Input

This section is unchanged relative to the corresponding section of Reference 8.1.1.

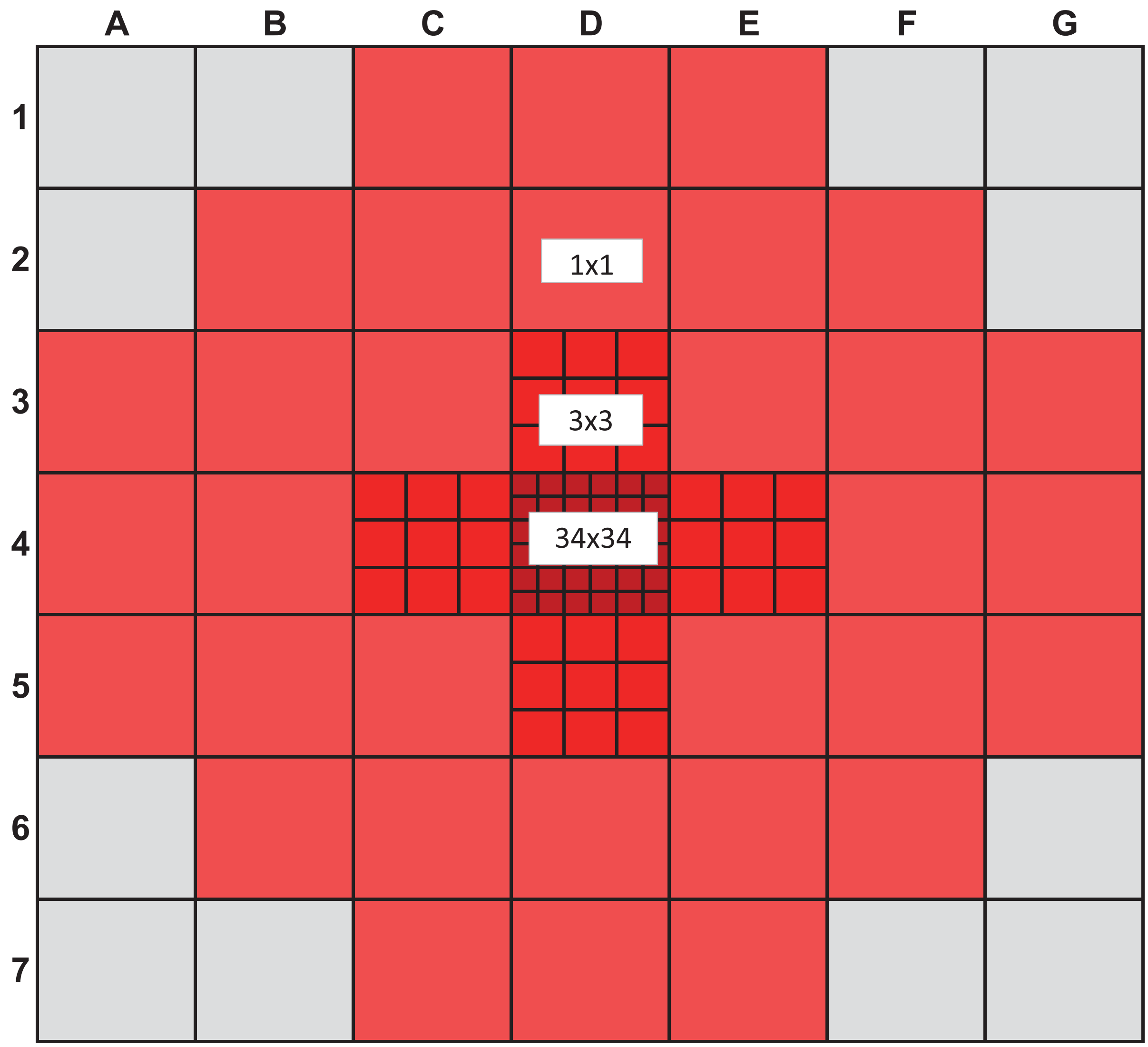
3.6 Fuel Design Specific Inputs

The application of form loss coefficients to the spacer grids is unchanged from the corresponding section of Reference 8.1.1. Changes to the axial model domain from that presented in Reference 8.1.1 are discussed in Section 3.7.2. With the change in the modeled axial domain, fuel assembly form loss coefficients are applied at the component centerline elevations.

3.7 Basemodel

The NuScale core contains 37 fuel assemblies as shown in the red squares of Figure 3-3. The methodology for statistical subchannel analysis utilizes a radial nodalization that models the full core and contains at least one detailed subchannel surrounded by progressively-lumped channels. An example of this is shown in the red squares of Figure 3-3. The basemodel is developed in a conservative manner and it does not represent a cycle-specific core; it is constructed in a way to preserve the limiting core conditions along with the operational envelope specified in the Technical Specifications. It is established based on the design peaking factors in combination with the limiting reactor coolant system global parameters. With this method, an artificial and bounding subchannel analysis model is appropriate, because the methodology ensures the limiting conditions of the cycle-specific core are captured by the basemodel.

Figure 3-3 VIPRE-01 Radial Nodalization



3.7.1 Radial Nodalization

The radial nodalization for the subchannel VIPRE-01 model represents the core at the level of detail required for the analysis. VIPRE-01 defines channels based on flow area, wetted perimeters, and heated perimeters, with subchannel communications modeled through gaps and centroid distances. The core radial nodalization must have at least one detailed subchannel with progression of lumped subchannels a few rod rows away from the hot subchannel, supported by sensitivity studies; these studies provide assurance that the hot rod and hot subchannel are able to resolve the local conditions while not significantly impacting MCHFR.

As an example, in Figure 3-3 the core is modeled with one fully detailed assembly, where all fuel rods and subchannels are modeled explicitly, and the remaining fuel assemblies progressively lump several subchannels into a single “lumped channel.” Specifically, assemblies directly adjacent to a fully detailed assembly are represented by nine lumped flow channels while all other assemblies are lumped into a single flow channel. This allows VIPRE-01 to be efficient in performing calculations, while the limiting subchannel local conditions fidelity is maintained.

In addition to the nodalization described, as well as that of Reference 8.1.1, limited flexibility is allowed. The following items must be satisfied in order for the radial nodalization to be acceptable:

- Reliable and converged solution
- Sufficient detail to resolve the dependent variables of CHF and CHF location (i.e., local flow, enthalpy, quality, and power)
- Hot rod and immediately adjacent fuel rods must be explicitly modeled in full detail
- At locations of node size changes, the relative difference in size (aspect ratio) must be sized in order to preserve fundamental assumptions of the numerical method (Reference 8.1.8)
- Each unique nodalization requires a set of sensitivity studies comparing it to more detailed nodalizations with no significant non-conservative impacts on calculated MCHFR

Justification for this example progressive-lumping approach is provided in Section 6.4.1.

3.7.1.1 Peripheral Assembly Geometry Modeling

The area of the core that is beyond the assembly pitch boundaries is not considered core flow that is available for heat transfer. Therefore, any area that is outside of the assembly pitch boundary line is considered bypass flow. This bypass fraction is reduced from the total primary system flow rate.

3.7.2 Axial Nodalization

The axial nodalization for the subchannel model is critical to capture the variance of the flow field throughout the height of the fuel assembly. Axial node size directly impacts the calculated MCHFR. The axial node size is selected to capture the flow field accurately.

The following items must be considered and balanced in order to determine the axial nodalization:

- Reliable and converged solution
- Sufficient detail to resolve the dependent variables of CHF and CHF location (i.e., local flow, enthalpy, quality, and power)

- Ensuring that losses are applied in the model consistent with their physical locations
- At locations of node size changes, the relative difference in heights (aspect ratio) is roughly similar in order to preserve fundamental assumptions of the numerical method (Reference 8.1.8)
- Smaller level heights in which flow diversions or asymmetric flow distributions may occur, such as just before the uppermost grid or at the core inlet, respectively

The axial domain in the subchannel model spans from the bottom of the lower core plate to above the upper core plate. At each component, the form loss coefficients are applied at the centerline elevation. Since VIPRE-01 inherently applies drag losses for the entire model, it can over-account for frictional losses outside of the axially rodded regions. These additional frictional losses are acceptable to simplify the modeling. An alternate modeling approach is to adjust the form loss for components outside of the fuel assembly to compensate for the additional drag losses modeled by VIPRE-01. Figure 3-6 is a graphical representation of the axial nodalization scheme for the subchannel basemodel.

The statistical subchannel basemodel axial nodalization is dependent upon having fuel design specific component losses as noted in Section 3.6. For implementing this methodology, component loss data from testing of fuel assembly components is required. The ability of the basemodel to properly resolve the flow distribution is ensured by utilizing pressure drop test data to define component losses. For example, the NuFuel-HTP2 fuel design underwent prototypic testing to characterize loss coefficients for each component of the fuel assembly, including spacer grids, bottom and top nozzles, and bare rod friction.

The axial nodalization of approximatively 2 inches is justified based on a sensitivity analysis (Section 6.4.3) in which different axial node sizes in the active fuel region are assessed. This sensitivity analysis demonstrates that the nodalization is appropriate to calculate the core thermal-hydraulic conditions and the MCHFR.

3.7.3 Review of Changes to Basemodel

The radial and axial modeling changes were evaluated relative to the basemodel described in Reference 8.1.1. A study examined the individual impacts of the

- radial nodalization
- axial nodalization
- axial domain
- application of the form losses for the upper and lower fuel nozzles at their respective locations
- application of the form losses for the upper and lower core plates at their respective locations

The critical linear heat generation rate (LHGR) is used to incrementally evaluate the impact of each individual model change relative to the Reference 8.1.1 basemodel until the final model matches the basemodel described in Section 3.7 of this report. The impact of the modeling changes are quantified as follows:

- {{

}}$^{2(a),(c),ECI}$

The values reported above represent the percent difference from the reference model described in Reference 8.1.1. The results demonstrate that most of the changes to the basemodel have a negligible impact to the figures of merit. The most impactful difference between the Reference 8.1.1 basemodel and the basemodel described in Section 3.7 of this report is the extension of the axial domain as shown in Figure 3-6.

The core inlet flow distribution (Section 3.12.9) is analytically defined at the bottom of the lower core plate consistent with the NPM design. The Reference 8.1.1 basemodel conservatively applied the flow distribution to the bottom of the fuel pins, which did not allow the flow to re-normalize before entering the limiting channel. Lateral flow within an assembly is appropriately modeled as there is no physical internal obstruction within the lower nozzle or lower core plate. Modeling the inlet flow distribution consistent with the NPM design provides a {{ }}$^{2(a),(c),ECI}$ in the local mass flux entering the limiting channel, which in turn, reduces hot channel enthalpy and enables higher heat fluxes prior to CHF. Application of the flow distribution at the axial domain boundary is consistent with the design and interface for system boundary conditions. In addition, analysis (e.g., CFD) to evaluate the uncertainty distribution should be based on the same domain definition of the subchannel model. This ensures applicability of the applied 5 percent penalty to account for the flow distribution uncertainty. If analysis shows that the penalty is insufficient it shall be increased.

The impact of the magnitude of the flow distribution uncertainty for both top- and bottom-peaked axial power shapes was examined. The results of this examination (Section 6.4.4) show that inlet flow penalties of up to 10% from uniform flow have less than {{ }}$^{2(a),(c),ECI}$ impact on MCHFR for both top and bottom-peaked power shapes. Therefore, it is appropriate to apply the inlet flow distribution of Section 3.12.9 to the extended axial domain boundary.

The subchannel model utilizes a modeling simplification for the extended axial domain. This simplification applies {{

}}$^{2(a),(c),ECI}$ The gap width of a subchannel multiplied by the nodal height (Δx) defines the lateral flow area available for crossflow. The impacts of this modeling simplification were examined by considering {{

}}$^{2(a),(c),ECI}$ These results demonstrate a lack of sensitivity to {{

}}$^{2(a),(c),ECI}$ and confirm that the simplified modeling approach is acceptable.

VIPRE-01 has been validated for resolving the flow and enthalpy distribution for the NuScale core in Reference 8.1.1. The axial and lateral flow equations are properly implemented such that flow redistribution benchmarks from a complete flow blockage show excellent agreement. The extension of the axial domain for the statistical subchannel basemodel is within the capability of VIPRE-01 such that local conditions can be accurately predicted when the component pressure drops are specified at their respective locations.

Figure 3-6 Axial Nodalization Diagram for Subchannel Basemodel (Not to Scale)

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}}2(a),(c),ECI

3.8 Boundary Conditions

This section and subsequent subsections are unchanged relative to the corresponding section of Reference 8.1.1.

3.9 Turbulent Mixing

This section is unchanged relative to the corresponding section of Reference 8.1.1.

3.10 Radial Power Distribution

The subchannel analysis uses a progressively-lumped basemodel as discussed in Section 3.7. To decouple the dependency of using a cycle-specific or time-in-life dependent radial power distribution, a conservative radial power distribution for a NuScale core that accounts for the worst distribution throughout the cycle is used. The limiting radial power distribution is bounding of the technical specifications limit on radial peaking factor. This must be confirmed for each fuel cycle loading pattern.

The radial power distribution is held constant throughout the transient for subchannel analyses.

3.10.1 Static Standard Review Plan Section 15.4 Analyses

For the Chapter 15 events where the radial power distribution can change during the event, particularly those that involve control rod movement, a modified radial distribution is used.

An augmentation factor is utilized to address this modification to the power distribution. It is defined in Equation 3-6 as the ratio of the maximum $F_{\Delta H}$ during the event to the initial condition. The augmentation factor is applied to the limiting assembly while a lower power assembly far away is reduced to preserve normalization of core power.

$$F_{\Delta H}^{Aug} = \frac{F_{\Delta H}^{Max}}{F_{\Delta H}^{Initial}} \qquad \text{Equation 3-6}$$

where:

$F_{\Delta H}^{Aug}$ = radial peaking augmentation factor

$F_{\Delta H}^{Initial}$ = maximum radial peaking at the beginning of the event

$F_{\Delta H}^{Max}$ = maximum radial peaking during the event

3.10.2 Time-Dependent Standard Review Plan Section 15.4 Analyses

This section is unchanged relative to the corresponding section of Reference 8.1.1.

3.10.3 Enthalpy Rise Hot Channel Factor

The core design has imposed a design limitation on the peak value of $F_{\Delta H}$, and therefore the highest value for any fuel rod throughout the full range of power, time in life, and allowed control rod positions. These values are defined in the development of the cycle design to allow the limiting peaking factor to increase for lower power level with the fit coefficients determined to bound the design peaking values as a function of power. This is inclusive of measurement uncertainties. The typical form of the equation is provided as example by Equation 3-8.

$$F_{\Delta H}^{SA} = A\ [1 + B\ (1 - P)] \qquad \text{Equation 3-8}$$

where:

$F_{\Delta H}^{SA}$ = Max. hot rod radial peaking analysis limit for safety analysis inclusive of the measurement uncertainties

P = Fraction of rated thermal power

A, B = Coefficients defined or confirmed during core cycle design to bound the design peaking values as a function of power

The subchannel methodology bounds any radial power distribution that occurs in the core prior to any AOO, infrequent event, or accident. The hot rod for the radial power distribution is set to the core operating limit peaking factor (or design limit) dependent upon the initial condition.

Uncertainties associated with $F_{\Delta H}$ are accounted for in the subchannel analysis as an increase on the core operating limit value. The uncertainties accounted for are measurement uncertainty related to the instrumentation used for monitoring, which is detailed in Section 3.12.2, and engineering hot channel uncertainty, which is detailed in Section 3.12.4. Increases in $F_{\Delta H}$ peaking for rodded configurations are also included as detailed in Section 3.10.5.

For cases evaluated at partial power levels, the $F_{\Delta H}$ distribution for the entire limiting assembly is scaled by Equation 3-8. The limiting assembly is peaked using Equation 3-8 and the lower power assembly is reduced by the necessary factor to maintain normalization of the core power.

3.10.3.1 Assembly Peripheral Row Peaking

In the subchannel methodology in Reference 8.1.1, a requirement is imposed on the core design that the peak $F_{\Delta H}$ rod for any assembly is not allowed to occur on the peripheral row. This requirement forces the hot subchannel to not occur on the outer row, as the outer row would be influenced by direct crossflow from the annulus channel between assemblies. While this channel is not truly simulated in the CHF tests, it is consistent with the CHF testing basis, therefore it was conservatively chosen to impose this design constraint.

However, for the statistical subchannel methodology described in this supplement, this restriction is no longer maintained.

It is acceptable for the peak $F_{\Delta H}$ rod in an actual core design to occur on a peripheral fuel rod in the assembly. The ratio of the flow area to heated area associated with a peripheral fuel rod location is larger, which results in a higher calculated MCHFR as compared to the smaller flow area to heated area ratio of a fuel rod channel in the interior of the assembly. The radial power distribution is determined as described in Section 3.10.6, which conservatively forces the analyzed hot rod location to occur in the limiting interior fuel rod location. This occurs either in a channel surrounded by four fuel rods, or a smaller flow area of the channel surrounded by three fuel rods and one unpowered guide tube rod.

3.10.4 Radial Flux Tilt

This section is unchanged relative to the corresponding section of Reference 8.1.1.

3.10.5 All Rods Out Power Dependent Insertion Limit Enthalpy Rise Hot Channel Factor

As described in Section 3.10.3, the power dependent radial peaking factor analysis limit inherently includes allowed control rod insertions. The deterministic methods in Reference 8.1.1 did not account for this allowed operational flexibility in this manner, and thus a specific PDIL-ARO factor was defined and accounted for in the subchannel method. In the method defined in this supplement, this factor is no longer applicable.

3.10.6 Determining the Bounding Radial Power Distribution

The radial power distribution for the subchannel basemodel is a bounding distribution expected to be used for future core designs that maintain a similar shuffle or loading pattern. This modeling method is justified from parametric sensitivity analysis in Section 6.4.2 of Reference 8.1.1, which confirms that the radial power distribution far removed from the hot subchannel has a negligible impact on the MCHFR results. Therefore, the use of a radial power distribution with the hot rod at the design peaking limit is sufficient for any distribution in a cycle-specific core.

The bounding radial power distribution used in the basemodel and most transients is not representative of the actual core conditions, and as a result, the determination of MCHFR for meeting the acceptance criterion is only applicable for the hot rod and subchannel. Thus, the purpose of the bounding radial power distribution is to capture the hot subchannel flow conditions, which are dependent upon the surrounding crossflow neighbor channels. A "flat" power distribution is one in which nearly all the rods provide similar power, and therefore, flow conditions and this power distribution limit the amount of turbulent mixing and diversion crossflow in the hot subchannel. This is conservative for thermal margin calculations.

The power distribution for an assembly may be characterized by its "peak-to-average" ratio, which is the maximum $F_{\Delta H}$ rod in an assembly divided by the average $F_{\Delta H}$ for the assembly. A value closer to unity denotes a flat power distribution. A spectrum of peak-to-average values for each assembly throughout the cycle burnup is utilized to determine a bounding distribution.

For each core design, each rod has a unique radial peak-to-average assembly ratio. In evaluating these ratios, assembly average relative power fraction values below a reasonable threshold (~1.1) are filtered out because the hot rod power is too low to be considered limiting for MCHFR. For example, when a core loading pattern contains fresh fuel on the periphery of the core, assemblies with a high $F_{\Delta H}$ rod have a large peak-to-average ratio due to the average $F_{\Delta H}$ rod being reduced by core leakage. These assemblies are considered non-limiting because of the enhanced inner-assembly crossflow that will be induced. For higher average-powered assemblies, the ratio of the peak-to-average ratio is flatter, because all the $F_{\Delta H}$ values are not far from the mean. These configurations are of interest because they work to reduce inner-assembly crossflow. The flattest peak-to-average ratio for assemblies of interest occur at high burnup steps where the maximum $F_{\Delta H}$ is quite small and thus considered non-limiting. Thus, a $F_{\Delta H}$ is required to be above a threshold (i.e., 1.25) for consideration in the peak-to-average ratio. Maximum $F_{\Delta H}$ values below this threshold are far below the analysis limit described in Section 3.10.3 and are excluded.

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}}2(a),(c),ECI

3. {{

}}2(a),(c),ECI

The process above ensures that the limiting subchannel and rod that experience the MCHFR are located near the center of the limiting assembly and not on the periphery of an assembly. An example radial power distribution utilizing the example values and implementing the defined steps is presented in Figure 3-7.

Figure 3-7 Example Radial Power Distribution for Core (Top) and Hot Assembly (Bottom)

{{

}}2(a),(c),ECI

3.10.7 Deterministic Radial Power Distribution

This section is no longer applicable to the statistical subchannel analysis methodology as the $F_{\Delta H}$ measurement uncertainty and $F_{\Delta H}$ engineering uncertainty are applied in the determination of the statistical CHF analysis limit (SCHFAL) as described in Section 3.12.

3.10.8 Axial Power Distribution

This section is unchanged relative to the corresponding section of Reference 8.1.1.

3.10.9 Standard Review Plan Section 15.4 Analyses

This section is unchanged relative to the corresponding section of Reference 8.1.1.

3.11 Numerical Solution

This section and associated subsections are unchanged relative to the corresponding section of Reference 8.1.1.

3.12 Statistical Method and Treatment of Uncertainties

There are several biases and uncertainties that are accounted for in subchannel safety analysis calculations, including those from analysis method, physical manufacturing design inputs to the model, and operating conditions. Each of these will be discussed in more detail to inform what each is composed of and how each is accounted for within the subchannel analysis methodology.

All of the uncertainties described in the sections below are summarized in Table 3-4 with a description of how each is applied and what distribution is recommended for use in generating random samples. The uncertainty distribution utilized in generating the statistical CHF analysis limit is justified in the implementing analysis. A normal distribution is applied when there are no firm bounds on the value or where the uncertainty is known to come from a stochastic process. For instance, measurement uncertainty for a thermocouple comes from the manufacturer and is generally based on sample testing, which naturally lends itself to a normal distribution. A uniform distribution is applied when well defined bounds are available and the probability of a particular value occurring is no greater than that of any other value (e.g., a measurement dead band or rod bow factor). There may be cases where neither of these distributions are ideal; engineering judgment will determine the most appropriate or conservative distribution.

3.12.1 Uncertainty in Analysis Method

The uncertainties in the analysis method consist of computer code uncertainty and CHF correlation uncertainty.

3.12.1.1 Computer Code Uncertainty

The computer code uncertainty pertains to the effects from using distinct discretization in axial and radial nodalization and also the approximations in the governing constitutive equations. Comparisons of code predictions to actual data for the condition ranges of application will usually eliminate the need for an explicit penalty on code and model uncertainties when the models used in the application are consistent with the models used in the development of the analysis limit. Most of this test validation work has been performed in VIPRE-01 already in

Reference 8.1.5. Additional validation work is performed in benchmarking VIPRE-01 to COBRA-FLX, an approved subchannel analysis code owned by Framatome with an approved SER, as described in Section 5.8 of Reference 8.1.1. The results of the benchmarks demonstrate that VIPRE-01 results are in good agreement with the AREVA COBRA-FLX code for conditions anticipated for NuScale applications. This includes various specific configurations of the NPM design concept at different powers, pressures, and temperatures, as well as axial and radial nodalizations that have been demonstrated to be acceptable.

CHF correlations are developed from the local conditions derived from a simulated subchannel model of the CHF test, using the subchannel software. This means that the uncertainty in the VIPRE-01 computer code is included in the CHF correlation itself. This has been the conventional industry practice and is appropriate. For this reason, no additional penalties for uncertainty in analysis method are added to the subchannel calculations.

3.12.1.2 Critical Heat Flux Correlation Uncertainty

The CHF correlation uncertainty is measureable and is included as part of the total CHF analysis limit. CHF correlations are developed from the local conditions derived from a simulated subchannel model of the CHF test, using the subchannel software.

Generally, a CHF correlation limit is determined in the process of correlation development. This limit prevents the occurrence of CHF on the hot rod with 95% probability at the 95-percent confidence level (95/95 level). The CHF measured-to-predicted (M/P) samples used to set this limit have a distribution that may or may not be parametric.

The 95/95 limit for the CHF correlation is utilized to create a normal distribution for sampling the CHF correlation uncertainty. The CHF correlation limit is based on a one-sided tolerance limit. For a normal distribution, the method for determining a one-sided upper tolerance limit is discussed in Section 9.12 of Ref. 8.1.4. The upper tolerance limit for CHF, L_{CHF}, is determined with:

$$L_{CHF} = \mu_s + k_1 \sigma_s \quad \text{Equation 3-10}$$

where:

μ_s is the sample mean,

σ_s is the sample standard deviation, and

k_1 is the one-sided tolerance factor based on the confidence level and the number of sample data.

The one-sided tolerance factor is determined using tables found in various statistical references such as Table T-11b of Ref. 8.1.4.

To create a bounding normal distribution for the CHF M/P data, the one-sided upper tolerance limit sets the CHF correlation limit. A standard deviation based on the CHF correlation limit, σ_{lim}, is determined based on a rearrangement of Equation 3-10 to calculate σ_{lim}:

$$\sigma_{lim} = \frac{(L_{CHF} - \mu_s)}{k_1} \qquad \text{Equation 3-11}$$

where:

L_{CHF} is the CHF correlation limit,

μ_s is the mean of the sample data, and

k_1 is the tolerance factor.

3.12.2 Uncertainty in Operating Conditions

The operating boundary conditions that are input into the subchannel analysis must account for all sources of margin and uncertainties related to them. Operating uncertainties account for process variable uncertainty, sensor accuracy and drift, and control deviation. The values for these uncertainties will be based on the instrumentation used for monitoring, and therefore are plant specific. Engineering judgement is made to incorporate reasonable uncertainties for the measured parameters.

The measurement uncertainties consist of those related to

- core thermal power (Σ_{CAL})
- core inlet flow (Σ_G)
- core inlet temperature (Σ_T)
- core exit pressure (Σ_P)
- enthalpy rise measurement uncertainty ($F^U_{\Delta H}$)

The correct accounting for uncertainties will be consistent between the system code and subchannel methodology, and care is taken to ensure the uncertainty is applied once to either the systems or subchannel calculations. Additional information on each of the operating boundary conditions and how they are applied in the statistical subchannel methodology is described in the following subsections. The nominal values for operating boundary conditions used in the calculation of the statistical analysis limit shall match the nominal values used in performing subchannel safety analysis calculations.

3.12.2.1 Core Thermal Power

Core thermal power is a function of the core calorimetric calculation and uncertainty. The core calorimetric calculation deduces core power from the temperature differential between cold-side and hot-side temperatures, the flow rate, and core fluid properties. The core thermal power Q_C is expressed as:

$$Q_C = Q_{CAL}\left(1 + \frac{\Sigma_{CAL}}{100}\right) \quad \text{Equation 3-12}$$

where:

Q_{CAL} is the calorimetric calculation of core power, and

Σ_{CAL} is the calorimetric measurement and calculation uncertainty (%).

The core thermal power uncertainty is accounted for either as a deterministic uncertainty or as part of the SCHFAL. When treated deterministically, the core thermal power uncertainty can be included in the system analysis that provides boundary condition input to the subchannel analysis or applied to nominal boundary conditions at the analysis interface. When incorporated into the SCHFAL, this uncertainty is included as part of the uncertainty distributions for the probabilistic parameters (Section 3.13.2). The calorimetric measurement and calculation uncertainty value is design specific.

3.12.2.2 Core Inlet Flow

The core inlet flow boundary condition must account for the appropriate bypass flow that is not available for heat transfer. The system-code transmitted flow boundary condition information will be that of RCS system flow to maintain compatibility with the systems transient methodology. The type of bypass mechanisms applicable for NuScale core subchannel analyses are described throughout Section 3.8.4 of Reference 8.1.1, with exact values defined in the core parameters report for a given core design. Core inlet flow is a function of the system flow and bypass flows, as well as flow measurement uncertainty. The core inlet flow G_{IN} is expressed as:

$$G_{IN} = G_{SYS} \cdot \left(1 + \Sigma_G - \frac{G_{RB}}{100} - \frac{G_{GT}}{100}\right) \quad \text{Equation 3-13}$$

where:

G_{SYS} is system flow,

G_{RB} is reflector bypass (%),

G_{GT} is bypass (%) in the fuel assembly guide thimbles/tubes, and

Σ_G is flow measurement uncertainty.

Core inlet flow uncertainty is accounted for either as a deterministic uncertainty or as part of the SCHFAL. When treated deterministically, the core inlet flow uncertainty can be included in the system analysis that provides boundary condition input to the subchannel analysis or applied to nominal boundary conditions at the analysis interface. When incorporated into the SCHFAL, this uncertainty is included as part of the uncertainty distributions for the probabilistic parameters (Section 3.13.2). The values for components of the uncertainty are design specific.

3.12.2.3 Core Inlet Temperature

Core inlet temperature uncertainty is a function of the cold-side temperature, temperature control dead band, and measurement uncertainty. The core inlet temperature T_{IN} is expressed as:

$$T_{IN} = T_{COLD} + \Sigma_T + T_{DB} \quad \text{Equation 3-14}$$

where:

T_{COLD} is cold-side temperature,

T_{DB} is the temperature controller dead band, and

Σ_T is the temperature measurement uncertainty.

The temperature dead band may be applied to a temperature other than T_{COLD} depending on the control system (i.e., T_{HOT} or T_{AVE}) and core inlet temperature distribution is considered to be flat per Section 3.8.6 of Reference 8.1.1.

Core inlet temperature uncertainty is accounted for either as a deterministic uncertainty or as part of the SCHFAL. When treated deterministically, the core inlet temperature uncertainty can be included in the system analysis that provides boundary condition input to the subchannel analysis or applied to nominal boundary conditions at the analysis interface. When incorporated into the

SCHFAL, this uncertainty is included as part of the uncertainty distributions for the probabilistic parameters (Section 3.13.2). The values for components of the uncertainty are design specific.

3.12.2.4 Core Exit Pressure

Core exit pressure is a function of the pressurizer pressure, pressure control dead band, measurement uncertainty, and the static head pressure drop between the pressurizer and the core exit. The core exit pressure P_{OUT} is expressed as:

$$P_{OUT} = P_{PRZ} + \Sigma_P + P_{DB} \qquad \text{Equation 3-15}$$

where:

P_{PRZ} is pressurizer pressure,

P_{DB} is the pressure controller dead band, and

Σ_P is the pressure measurement uncertainty.

The hydrostatic head from the core exit to the pressurizer should be determined and provided as a boundary condition from a systems code such as NRELAP5.

Core exit pressure uncertainty is accounted for either as a deterministic uncertainty or as part of the SCHFAL. When treated deterministically, the core exit pressure uncertainty can be included in the system analysis that provides boundary condition input to the subchannel analysis or applied to nominal boundary conditions at the analysis interface. When incorporated into the SCHFAL, this uncertainty is included as part of the uncertainty distributions for the probabilistic parameters (Section 3.13.2). The values for components of the uncertainty are design specific.

3.12.2.5 Enthalpy Rise Measurement Uncertainty

The $F_{\Delta H}$ measurement uncertainty ($F^U_{\Delta H}$) accounts for uncertainties in the instrumentation for protecting Technical Specification limits. The default method accounts for this in the SCHFAL, but when the radial peaking factor is defined as an analytical limit (as opposed to an operating limit), no additional uncertainty is incorporated (Section 3.10.3).

The enthalpy rise measurement uncertainty is applied to the SCHFAL (Section 3.13.2).

3.12.3 Uncertainty in Physical Data Inputs

Physical data that is used in the VIPRE-01 subchannel analysis has an uncertainty and must be accounted for in thermal margins analysis because small deviations from nominal are allowed. The items that are generally applicable to VIPRE-01 and subchannel calculation methods are related to initial manufacturing tolerances and changes to dimensions throughout the life of fuel:

- enthalpy rise engineering uncertainty ($F_{\Delta H}^{E}$)
- heat flux engineering uncertainty (F_{Q}^{E})
- LHGR engineering uncertainty (F_{LHGR}^{E})
- radial power distribution uncertainty ($F_{\Delta H}^{NRF}$)
- fuel rod bowing and assembly bowing uncertainties ($F_{\Delta H}^{RB}$)
- core inlet flow distribution uncertainty
- core exit pressure distribution uncertainty

The treatment, in the VIPRE-01 inputs or post-processing thermal margin determination, for each above uncertainties is described in the follow sections. Values for these uncertainties are design specific.

3.12.4 Enthalpy Rise Engineering Uncertainty

The enthalpy rise engineering uncertainty ($F_{\Delta H}^{E}$) is a penalty factor that is applied on the hot channel to account for fabrication uncertainties related to allowable manufacturing tolerances. This factor is also referred to as the enthalpy rise hot channel factor. The enthalpy rise hot channel factor accounts for variations in pellet diameter, pellet density, enrichment, fuel rod diameter, fuel rod pitch, rod bowing, inlet flow distribution, flow redistribution, and flow mixing.

The fuel vendor divides this into two factors, $F_{\Delta H1}^{E}$, referred to as the pin power effect, and $F_{\Delta H2}^{E}$, which is the flow area factor impact on enthalpy rise. The fuel vendor provides the $F_{\Delta H1}^{E}$ channel factor while $F_{\Delta H2}^{E}$ is dependent upon the subchannel modeling and methodology applied.

The rod power part of the hot channel factor, $F^{E}_{\Delta H1}$, accounts for fuel stack length and uranium loading uncertainties. The $F^{E}_{\Delta H2}$ hot channel factor is dependent upon the VIPRE-01 modeling and two phase flow correlations when used in combination with accounting for uncertainties in the subchannel flow area due to fuel rod pitch and outer diameter variations.

Both sources of enthalpy rise engineering uncertainty are applied to the SCHFAL (Section 3.13.2).

3.12.5 Heat Flux Engineering Uncertainty

The heat flux engineering uncertainty factor (F^{E}_{Q}) is a penalty factor that accounts for the small manufacturing uncertainties that affect the local heat flux. This factor is often referred to as the heat flux hot channel factor. The heat flux hot channel factor is affected by variations in fuel enrichment, pellet density, pellet diameter, and fuel rod surface area. The value of this uncertainty parameter is provided by the fuel vendor.

The use of a non-uniform axial factor on the critical heat flux value is sufficient to account for any reasonable non-uniformities that develop in the heat flux distribution. NuScale CHF correlations use a non-uniform axial factor, referred to as the F-Factor, to account for non-uniform axial heating. However, the heat flux engineering uncertainty is included in the SCHFAL for conservatism.

The heat flux is intended to be penalized so that the local heat flux uncertainty does not affect the channel enthalpy rise. There is no method to directly account for this in VIPRE-01, therefore this uncertainty is applied to the CHFAL in the SCHFAL methodology. Heat flux engineering uncertainty samples, $P_{HF}(i)$, are taken on the range of 0% to the maximum heat flux engineering factor for a one-sided distribution. Using a one-sided distribution is appropriate because the heat flux engineering factor always provides a CHF penalty. The sample heat flux engineering penalty factor, $F^{E}_{Q}(i)$, is calculated with:

$$F^{E}_{Q}(i) = 1 + \frac{P_{HF}(i)}{100} \qquad \text{Equation 3-16}$$

where:

$P_{HF}(i)$ is sample heat flux engineering penalty in %.

The heat flux engineering uncertainty is sampled and applied to the SCHFAL (Section 3.13.2).

3.12.6 Linear Heat Generation Rate Engineering Uncertainty

The F^{E}_{LHGR} hot channel factor remains applicable for PLHGR FCM calculations. This is not applied to the CHFR calculations because it is accounted for in the heat flux hot channel factor (F^{E}_{Q}).

The linear heat generation rate engineering uncertainty factor is applied as a penalty on the peak LHGR (Section 4.5.1 of Reference 8.1.1).

3.12.7 Radial Power Distribution (SIMULATE5) Uncertainty

The radial power distribution uncertainty is related to the neutronics code that is used for the radial power distribution inputs. A sensitivity study for different power distributions of the NuScale core in Section 6.0 of Reference 8.1.1 showed that rod powers a few rod rows beyond the limiting hot rod/channel have a negligible impact on the MCHFR. The hot rod in the subchannel model is placed at the radial peaking analysis limit (see Section 3.10.3) and the neutronic code uncertainty is accounted for in the check of the core design to the analysis limit.

No radial power distribution penalty is applied to the subchannel analysis evaluation model or SCHFAL.

3.12.8 Fuel Rod and Assembly Bow Uncertainty

3.12.8.1 Fuel Rod Bow Uncertainty

Rod bow penalty samples, P_{RB} (i), are taken from a uniform distribution on the range of 0% to the maximum rod bow penalty. The rod bow penalty is conservatively assumed to only provide a CHF penalty. The sample rod bow penalty factor, $F^{RB}_{\Delta H}(i)$, is calculated with:

$$F^{RB}_{\Delta H}(i) = 1 + \frac{P_{RB}(i)}{100} \qquad \text{Equation 3-17}$$

where P_{RB} (i) is sample rod bow penalty in %.

The fuel rod bow uncertainty is applied to the SCHFAL (Section 3.13.2).

3.12.8.2 Assembly Bow Uncertainty

Assembly bow is a complex phenomenon that results in axial distortions of the fuel assembly. The large flux gradients along the outer assemblies, if higher reactivity fuel is loaded there, increases the potential for assembly bow to occur. As defined in Reference 8.1.6, CHF penalties are only applied for rod bow and not assembly bowing because bowing of a full assembly will preserve the flow area. No penalties for assembly bowing are considered in CHF calculations.

3.12.9 Core Inlet Flow Distribution Uncertainty

This section is unchanged relative to the corresponding section of Reference 8.1.1.

The core inlet flow distribution uncertainty is applied to the limiting channels in the basemodel.

3.12.10 Core Exit Pressure Distribution Uncertainty

This section is unchanged relative to the corresponding section of Reference 8.1.1.

No uncertainty for core exit pressure distribution is applied.

3.13 Bias and Uncertainty Application within Analysis Methodology

In the NuScale statistical subchannel methodology, random uncertainties are combined together statistically and accounted for within the statistical CHF analysis limit (SCHFAL). A summary of the uncertainties discussed throughout this section is provided in Table 3-4. Figure 3-2 visually represents the MCHF limits and presents a pictorial meaning to the margins.

3.13.1 Statistical Methods

The statistical methods utilized are predominantly based on Reference 8.1.4, which include, but are not limited to non-parametric confidence intervals and assurance-to-quality (A/Q) of 95/95.

For all statistical tests and processes the level of significance, α, is 0.05. For all parameters used, a justification must be provided for the distribution used. Evidence or theoretical reasoning must be provided for parameters that sample from a uniform distribution. Parameters that are directly measured will typically utilize a normal distribution with proper justification.

3.13.1.1 Uniform Distribution

A uniform distribution models situations where a random variable takes on a value from a specified interval with equal probability. The density function for a uniform distribution is illustrated in Figure 3-10. This demonstrates that on the range a to b, all points have the same probability of occurring. More information regarding the uniform distribution may be found in Section 7.2 of Reference 8.1.4. A randomly generated value from a uniform distribution on the range a to b, U(a,b), is determined with:

$$U(a,b) = RND(0,1) \cdot (b - a) + a \qquad \text{Equation 3-18}$$

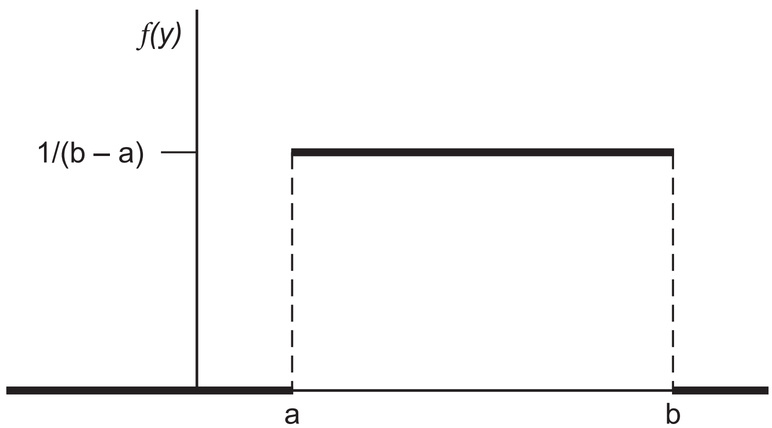
where:

RND(0,1) is a randomly generated value on the range **0** to **1**,

a is the lower bound of the range, and

b is the upper bound of the range.

Figure 3-10 Density Function of the Uniform Distribution



3.13.1.2 Normal Distribution

The use of the normal distribution is ubiquitous in statistics as it provides a model for many natural phenomena. The density function for the normal distribution is illustrated in Figure 3-11 below. Two randomly generated values from a normal distribution, Z_1 and Z_2, are determined with the Box-Muller transformation (Section 27.5 of Reference 8.1.4).

$$Z_1 = \sqrt{-2\ln(U_1)}\cos(2\pi U_2)$$

$$Z_2 = \sqrt{-2\ln(U_1)}\sin(2\pi U_2)$$

Equation 3-19

where U_1 and U_2 are randomly generated values from a uniform distribution, U(0,1), using Equation 3-18 above. The two z values calculated with the Box-Muller transformation can both be shown to belong to the normal distribution given enough samples. Uncertainty values N1 and N2 may be determined from the two samples above with:

$$N_1(\mu,\sigma) = \sigma Z_1 + \mu$$

Equation 3-20

$$N_2(\mu,\sigma) = \sigma Z_2 + \mu$$

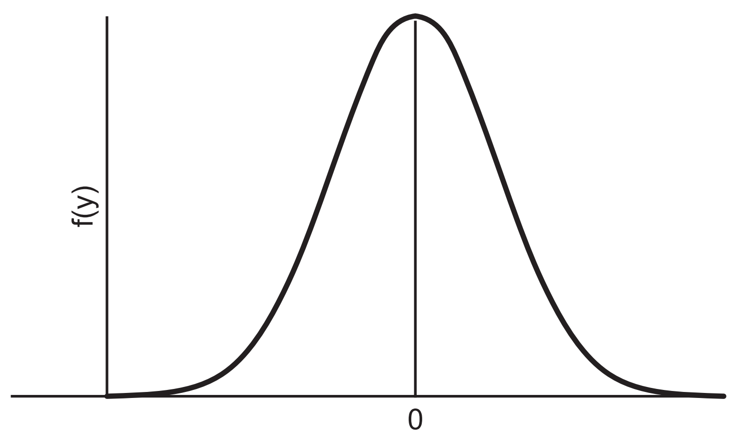
where:

σ is standard deviation, and

μ is the mean value.

In most cases *μ* is considered to be 0, unless some bias is noted.

Figure 3-11 Density Function of the Normal Distribution



3.13.1.3 Quality Assurance Sampling

The specific criteria necessary to meet the requirements of GDC 10 are that "*there should be a 95-percent probability at the 95-percent confidence level that the hot rod in the core does not experience a boiling crisis during normal operation or AOOs.*" This amounts to a quality assurance statement equivalent to an A/Q of 95/95. Quality assurance is discussed in detail in Section 24.8, 24.9, 24.10, and 24.11 of Reference 8.1.4. Some general rules for A/Q sampling are:

- Sample size shall be determined before sampling begins and the entire set will be either accepted or rejected
- The set shall be unequivocally defined before sampling begins
- The set is made up of similar items that are treated alike
- If the set is comprised of several sub-sets, each sub-set must be addressed separately

While A/Q sampling is more generally used in manufacturing to determine whether a lot is acceptable based on statistically sampling of the lot, the concept may be extended to the determination of data bounds. For instance, if the lot is considered to be all occurrences of CHF then statistical sampling is performed on a subset of CHF, namely the CHF test results. Once a CHF correlation is developed it is imperative to create a limit that assures an A/Q of 95/95 to meet GDC 10. In this example, the limit is set to be greater than or equal to 95% of the data with 95% confidence. This same principle can be applied to any data subset that is representative of a larger set.

The sample size is fixed in advance, and should be informed by the number of failures, or in the CHF example above the number of data above the limit, that are deemed acceptable. Using the framework set forth in Section 24.10 of Reference 8.1.4 for determining the allowable number of failures for a given sample size n, utilizing a binomial distribution, Table 3-3 is created. This table provides the number of samples required to meet a particular number of allowable failures, up to 99.

Table 3-3 Sample Size versus Number of Allowable Failures

fail	n	fail	n	fail	n	fail	n
0	59	25	694	50	1260	75	1810
1	93	26	717	51	1282	76	1832
2	124	27	740	52	1305	77	1854
3	153	28	763	53	1326	78	1876
4	181	29	786	54	1348	79	1898
5	208	30	809	55	1371	80	1919
6	234	31	832	56	1393	81	1941
7	260	32	855	57	1415	82	1963
8	286	33	877	58	1437	83	1985
9	311	34	900	59	1460	84	2006
10	336	35	923	60	1481	85	2029
11	361	36	945	61	1503	86	2050
12	386	37	968	62	1525	87	2071
13	410	38	991	63	1547	88	2093
14	434	39	1013	64	1569	89	2115
15	458	40	1036	65	1591	90	2138
16	482	41	1058	66	1613	91	2158
17	506	42	1081	67	1635	92	2180
18	530	43	1103	68	1657	93	2202
19	554	44	1126	69	1679	94	2223
20	577	45	1148	70	1701	95	2245
21	601	46	1170	71	1723	96	2267
22	624	47	1193	72	1745	97	2288
23	647	48	1215	73	1766	98	2310
24	671	49	1237	74	1788	99	2331

3.13.2 Statistical CHF Analysis Limit

When not considering uncertainties, a fuel rod is considered to fail when MCHFR reaches 1.0. {{ }}2(a),(c),ECI

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Figure 3-12 CHF Analysis Limit Calculation Flow Chart

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3.13.2.1 Best-Estimate Model Reference State-Point

Determining the overall uncertainty of the SCHFAL requires {{

}}2(a),(c),ECI The range of the sampled state-points should be constructed such that it is ensured that the time of MCHFR and the associated state-point within a given transient are bounded by the domain of which the SCHFAL was developed. Figure 3-13 provides a sample of this for conceptual purposes. The red shaded regions represent the applicability domain for the current NSP4 CHF correlation. The red-hatched regions represent the domain that may be of interest for the transient space to which the SCHFAL may be appropriately applied. If the transient domain is discovered to go outside the SCHFAL applicability range then the limit must be re-derived considering the wider range.

Figure 3-13 Example Sample SCHFAL Domain

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}}2(a),(c),ECI

Figure 3-14 {{ }}2(a),(c),ECI

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3.13.3 ΔMCHFR Calculation Process

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}}2(a),(c),ECI Equation 3-28

3.13.4 Calculating the Statistical CHF Analysis Limit

The SCHFAL is a value determined to ensure that a sufficient number of probabilistic samples of the CHFAL fall below the SCHFAL at the 95/95 level. A single SCHFAL is calculated at the 95/95 level using the SCHFAL(*i*) values calculated with Equation 3-24. A non-parametric statistical method is used to determine the SCHFAL, so the CHFAL samples are ranked in ascending order and the number of allowable values above the SCHFAL are determined based on the number of overall converged CHFAL samples using Table 3-3. For a sample size of 500 CHFAL samples, the number of acceptable values above the SCHFAL would fall between 16 and 17 values. The lower (i.e., 16th) value is chosen to ensure compliance with the 95/95 criterion. From the 500 ordered samples the 484th (500-16) ordered value sets the SCHFAL.

Assessments of the complete sample and subsets of the sample are performed to ensure that the SCHFAL is sufficient to cover all subregions of the data. Subsets of the CHFAL samples are created by binning the CHFAL samples. These bins are sized to achieve as close to an even distribution of data in each subset as possible. Each bin is processed with the non-parametric method described above and a SCHFAL for each bin is calculated. The maximum SCHFAL of the bins is considered the limiting SCHFAL because it covers all of the bins. This same process is performed for other relevant parameters.

3.13.5 Summary of Bias and Uncertainty Treatment

To summarize the uncertainties and biases applied in the statistical subchannel methodology, Table 3-4 is provided. The uncertainty bias for the boundary conditions are listed as being accounted for either in the system transient analysis boundary conditions provided using systems transient methodology or in the statistical analysis limit. The table provides example distributions for the statistically treated parameters;

however, the distribution applied for each shall be justified in the implementing analysis based on the source data for each parameter. When performing steady-state analyses for CHF evaluation or analyses that don't explicitly involve system transient methodology, these uncertainties should be applied explicitly in the subchannel application.

Table 3-4 Summary of Example Subchannel Methodology Parameter Treatment

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Table 3-4 Summary of Example Subchannel Methodology Parameter Treatment (Continued)

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3.14 Mixed Core Analysis

This section is unchanged relative to the corresponding section of Reference 8.1.1.

3.15 Methodology-Specific Acceptance Criteria

This section is unchanged relative to the corresponding section of Reference 8.1.1, with one exception. The MCHFR may occur on a peripheral subchannel of the assembly, as discussed in Section 3.10.3.1.

4.0 Transient-Specific Applications Methodologies

This section is unchanged relative to the corresponding section of Reference 8.1.1. A criterion for ensuring fuel integrity is MCHFR. The SCHFAL calculated using the methodology in this supplemental topical report is used to evaluate transient margin by demonstrating the transient-specific MCHFR is larger than the SCHFAL.

5.0 VIPRE-01 Qualification

This section is unchanged relative to the corresponding section of Reference 8.1.1.

6.0 Example Calculation Results

The example calculation analyses and results presented in Reference 8.1.1 are provided to demonstrate the applicability of the subchannel methodology. This topical report supplement does not repeat the example calculations since the examples provided in Reference 8.1.1 continue to provide a suitable demonstration of subchannel analysis. Note that the sensitivity analysis presented in this topical report uses a different set of inputs than those presented in Reference 8.1.1 since neither methodology requires specific input values. It is further noted that Section 6.2 of Reference 8.1.1 examined multiple basemodel scenarios which are not applicable to this topical report; however, that section continues to provide an acceptable example of steady-state subchannel analysis. A subset of the sensitivity analysis has been reperformed for the updated radial nodalization (Section 6.4.1) and axial nodalization (Section 6.4.3) discussed in Section 3.7. Additionally, the inlet flow distribution sensitivity analysis (Section 6.4.4) has been reperformed. No additional changes are needed in the corresponding section of Reference 8.1.1.

6.4 Sensitivity Analysis

The following sensitives are performed by comparing the critical linear heat generation rate to determine impacts of the revised model nodalization. Results from specific sensitivities are compared to a reference basemodel to quantify the impacts.

6.4.1 Radial Geometry Nodalization

A sensitivity analysis is performed to demonstrate that the radial nodalization outside the hot channel does not have significant impact on the local hot channel results. To demonstrate this, the sensitives in Table 6-17 are performed considering various levels of resolution of the subchannels outside the modeled hot assembly.

Table 6-17 Radial Nodalization Sensitivities

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Table 6-17 Radial Nodalization Sensitivities (Continued)

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Figure 6-15 Single Fully Detailed Hot Assembly Model

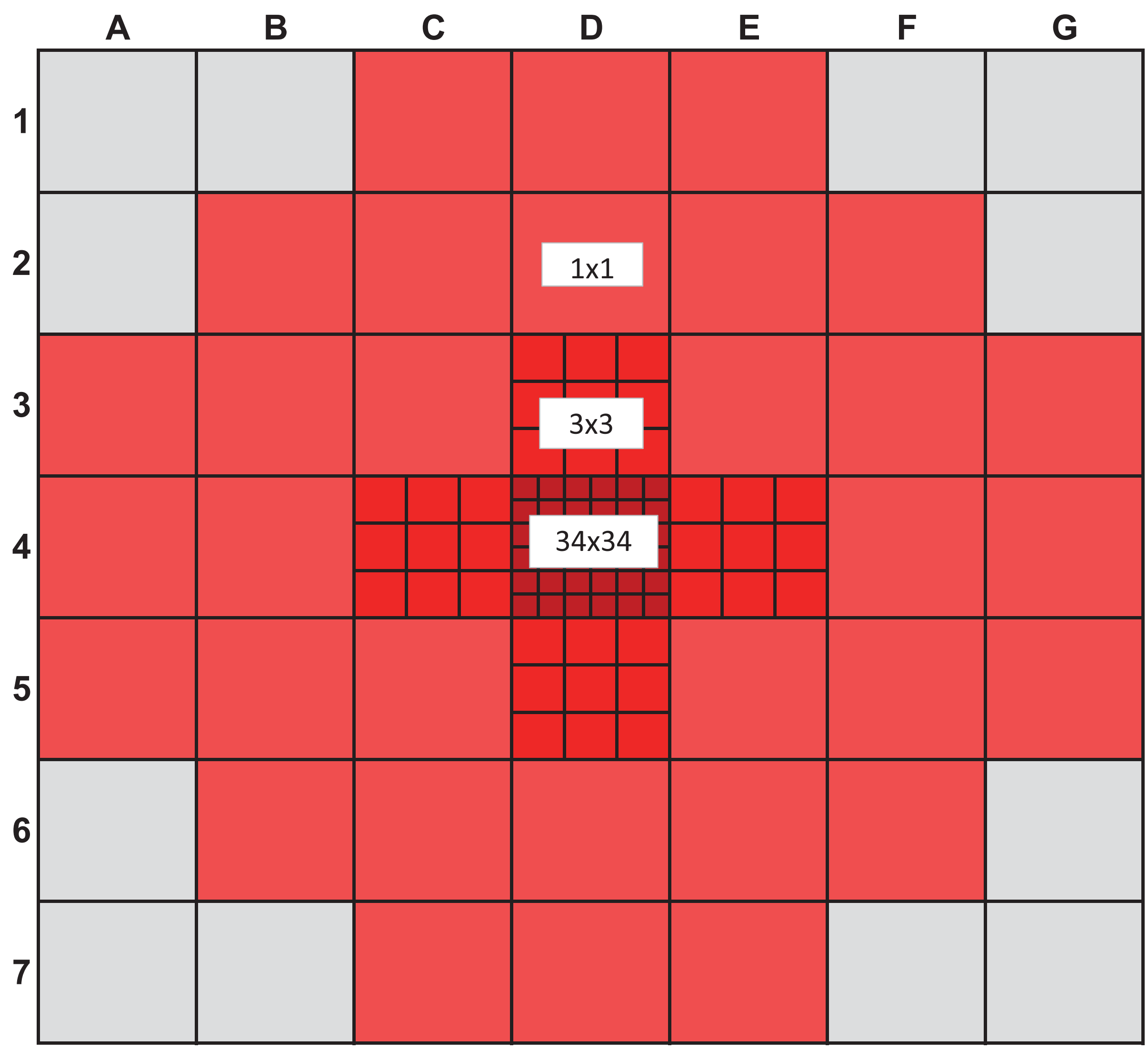

Figure 6-16 Nine Detailed Assemblies Model

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Figure 6-17 Twenty-Five Detailed Assemblies Model

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Figure 6-18 Fully Detailed Core Model

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Figure 6-19 Full Core Lumped Model

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The results are presented in Table 6-18.

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}}2(a),(c),ECI

Table 6-18 Radial Geometry Nodalization Linear Heat Generation Rate Sensitivity Results

{{

}}2(a),(c),ECI

{{

}}2(a),(c),ECI

6.4.3 Axial Geometry Nodalization

A sensitivity analysis is performed (Table 6-19) to demonstrate a reasonable and consistent solution can be obtained considering both accuracy and performance.

Sensitivities inform the appropriate axial nodalization resolution required to:

- Ensure a reliable and converged solution
- Ensure nodalization resolves the dependent variables of CHF and CHF location (i.e., local flow, enthalpy, quality, and power)
- Ensure that losses are applied in the model near their appropriate locations

Table 6-19 Axial Nodalization Sensitivities

{{

}}2(a),(c),ECI

Table 6-20 Axial Geometry Nodalization Linear Heat Generation Rate Sensitivity Results

{{

}}2(a),(c),ECI

{{

}}2(a),(c),ECI

6.4.4 Inlet Flow Distribution

A sensitivity analysis is performed to examine the impact of inlet flow distributions on the figures of merit for the subchannel analysis. The sensitivities examined varying magnitudes of flow reduction to the hot assembly as well as varying the reduction of flow in assemblies surrounding the hot assembly. Each sensitivity case considered both bottom and top peaked power profiles. Table 6-21 summarizes the sensitivities performed.

Table 6-21 Description of Inlet Flow Distribution Sensitivities

{{

}}2(a),(c),ECI

The results of the cases are provided in Table 6-22 and show {{

}}2(a),(c)

{{

}}2(a),(c),ECI

Table 6-22 Results Summary of Inlet Flow Distribution Sensitivities

{{

}}2(a),(c),ECI

7.0 Summary and Conclusions

An overview of the statistical methodology utilized for steady-state and transient subchannel analysis has been presented. Design calculations will use this methodology for assessing thermal margin and to determine if fuel failure will occur due to inadequate heat removal capability through evaluation of the critical heat flux ratio and fuel centerline melt. The methodology is developed to meet relevant acceptance criteria of Section 4.4 and Chapter 15 of the SRP.

The thermal design analysis methodology for NuScale subchannel analysis has been presented with the basis for the statistical application of uncertainties. A progressively lumped channel model is used to resolve the desired enthalpy and flow field, with focus on the hot channel. This methodology is applied as a standard technique for modeling steady-state calculations and transients. Sensitivity analysis is provided to demonstrate applicability of the methodology. Descriptions of the model nodalization, boundary conditions, radial power distributions, and uncertainties and biases are provided.

7.1 VIPRE-01 Safety Evaluation Report Requirements

This section is unchanged relative to the corresponding section of Reference 8.1.1.

The NuScale application of VIPRE-01 continues to fulfill the requirements specified in the generic VIPRE-01 SER (Reference 8.1.7).

7.2 Criteria for Establishing Applicability of Methodology

The generalized methodology presented in this topical report supplement is based upon modeling assumptions. The following set of criteria for establishing the applicability of this methodology is provided. An applicant or licensee that uses the methodology of this supplement must satisfy these criteria in order to establish applicability. Any deviation from these criteria must be defined and justified.

7.2.1 General Criteria

The following criteria are required for a valid MCHFR calculation:

- The local mass flux, equilibrium quality, and pressure at the location and time of MCHFR must be within the correlation applicability range.
- The hot rod from the VIPRE-01 MCHFR calculation must be the rod with the highest $F_{\Delta H}$ peaking factor.
- The VIPRE-01 calculation must satisfy all selected convergence criteria for the results to be considered valid. If convergence cannot be met with the selected default values or methods, justification must be provided to ensure that the relaxed acceptance criterion does not result in incorrect or premature results. If the calculation still does not converge, an assessment of the calculated results needs to be provided to prove acceptability.

- Axial nodalization within the region in which MCHFR is predicted to occur must be sufficiently small to resolve the flow field such that parametric sensitivity analysis results in a change of less than five CHF points for a halving of the nodalization size. Additionally, an aspect ratio (ratio of adjacent cell heights) of less than three must be maintained.
- The RECIRC numerical solution must be used.
- Heat transfer and two-phase flow correlation options defined in Table 5-7 of Reference 8.1.1 must be used.
- Rate of depressurization must be below 20 psi/second.
- Fast transients require that simulations are performed in sufficiently small time steps to capture the CHFR behavior adequately.
- Water properties for temperature and specific volume must be valid within the VIPRE-01 application range.
- Fuel pressure drop must be significantly less (by a factor of 10) than the minimum system pressure evaluated with the uniform pressure option or the local pressure drop option must be used.

7.2.2 Critical Heat Flux Correlation

The methodology presented in this report is independent of a specific CHF correlation. However, any application of the subchannel methodology is limited by the following restrictions:

- The application must explicitly state that an approved CHF correlation is used.
- The CHF correlation must be used within its applicable parameter ranges.
- Simulated local conditions in the subchannel analysis must be consistent with or bounded by the local conditions for CHF testing, CHF correlation development, and CHFR analysis limit development.
- The same two-phase flow model options must be used for CHF correlation and analysis limit development.
- CHF correlation and corresponding inputs must be those which are applicable to the fuel design (including spacer grids) being analyzed.
- Fuel design and CHF correlation dependent (or bounding) turbulent mixing coefficient (ABETA) must be defined and utilized in the analysis.

7.2.3 Nuclear Analysis Discipline Interface

The nuclear analysis interfaces are:

- Cycle-specific confirmations of all bounding analysis limits must be defined in the core parameter report for a specific core design.

7.2.4 Transients Discipline Interface

The transient analysis interfaces are:

- For events in which one or more parameters are outside the CHF correlation range applicability, such as low flow rate after reactor trip, the transients discipline calculation must ensure all SAFDLs are satisfied via long term cooling methodology.
- Either the system transients analysis or the subchannel analysis must account for operating parameter measurement uncertainties in core power, system flow, inlet temperature, and core exit pressure.
- The flow boundary condition must be provided as system flow (as opposed to core flow) such that the subchannel analysis accounts for all components of bypass flow consistent with methodology.

7.3 Cycle-Specific Confirmations

In general, the subchannel method presented is generic to a given core design (i.e., not cycle-specific) and specific analyses utilizing the methods do not need to be repeated each cycle if the cycle remains within evaluated bounds. However, each unique core design is checked to ensure the subchannel analysis remains applicable. As a result, the following cycle-specific confirmations with respect to subchannel analysis only (i.e., other confirmations may be required) are performed for each cycle:

- Cycle-specific axial power shapes are bounded by those used in the generic bounding analysis
- Radial nodalization appropriately treats the symmetry of the core design
- Hot full power $F_{\Delta H}$ at all exposures is less than analysis limit $F_{\Delta H}$
- Changes to radial peaking as a result of allowed control rod insertion is appropriately treated in an analysis limit or subchannel input
- Fission product (i.e., xenon) transients that disturb symmetric power peaking preserve radial tilt less than allowed by Technical Specifications
- Asymmetric reactivity anomaly events analyses confirm that the maximum cycle-specific augmentation factor calculated is bounded by that used in the generic bounding analysis

7.4 Key Fuel Design Interface Requirements

The subchannel analysis methodology presented is generic to a given fuel design, and does not need to be reformulated for a different design. However, each unique fuel design requires significant inputs into the subchannel analysis. The following is a minimum list of required fuel design inputs that must be provided for each fuel design evaluated with this methodology:

- An approved CHF correlation valid for the fuel design
- Basic geometry, flow loss coefficients, and friction factors

- Guide tube bypass flow
- Heat flux engineering uncertainty factor
- Linear heat generation rate engineering uncertainty factor
- Assembly and rod bow uncertainty factors
- Calibration of the VIPRE-01 fuel rod conduction model to a fuel performance code
- Melting temperature equation to calculate fast transient FCM safety limit

7.5 Unique Features of the NuScale Design

This section is unchanged relative to the corresponding section of Reference 8.1.1, with the exception of Table 7-2, which is updated.

Table 7-2 Comparison of NuScale Reactor Core Design to Conventional PWR

Parameter	Units	NuScale	Typical 4-Loop PWR (Ref. 8.2.39)
Core Thermal Output	MW	160-250	3565
System pressure	psia	1850-2000	2250
Thermal design flow rate	Mlbm/hr	5-6	139.4
Core average coolant mass velocity	Mlbm/hr-ft^2	0.5-0.6	2.41
Core inlet coolant temperature	°F	470-500	556.8
Core average rise in reactor core	°F	90-125	63.2
Core average heat flux	MBtu/hr-ft^2	0.02-0.03	0.206
Local peak heat flux	MBtu/hr-ft^2	0.03-0.05	0.515
Min. CHFR at nominal conditions	Ratio	>5	2.47

8.0 References

8.1 Referenced Documents

8.1.1 NuScale Power, LLC, “Subchannel Analysis Methodology,” TR-0915-17564-P-A, Revision 2.

8.1.2 NuScale Power, LLC, “NuScale Power Critical Heat Flux Correlations,” TR-0116-21012-P-A, Revision 1.

8.1.3 NuScale Power, LLC, “Applicability Range Extension of NSP4 Critical Heat Flux Correlation, Supplement 1 to TR-0116-21012-P-A, Revision 1,” TR-107522-P-A, Revision 1.

8.1.4 U.S. Nuclear Regulatory Commission, “Applying Statistics,” NUREG-1475, Revision 1, March 2011.

8.1.5 C.W. Stewart et al., NP-2511-CCM-A, Volume 2, User's Manual, Revision 4.5, “VIPRE-01 A Thermal-Hydraulic Code for Reactor Cores,” Computer Code Manual, February 2014.

8.1.6 NuScale Power, LLC, “Applicability of AREVA Fuel Methodology for the NuScale Design,” TR-0116-20825-P-A, Revision 1.

8.1.7 “Safety Evaluation by the Office of Nuclear Reactor Regulation Relating to VIPRE-01 Mod 02 for PWR and BWR Applications,” EPRI-NP-2511-CCM-A, Revision 3, October 30, 1993.

8.1.8 C.W. Stewart et al., NP-2551-CCM-A, Volume 1, Mathematical Modeling, Revision 4.5, “VIPRE-01 A Thermal-Hydraulic Code for Reactor Cores,” Computer Code Manual, February 2014.

Section C

RAI Number	eRAI Number	NuScale Letter Number
N/A	N/A	There were no RAI requests associated with TR-108601, Rev 4

Enclosure 3:

Affidavit of Carrie Fosaaen, AF-163416

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www.nuscalepower.com

NuScale Power, LLC

AFFIDAVIT of Carrie Fosaaen

I, Carrie Fosaaen, state as follows:

(1) I am the Vice President of Regulatory Affairs of NuScale Power, LLC (NuScale), and as such, I have been specifically delegated the function of reviewing the information described in this Affidavit that NuScale seeks to have withheld from public disclosure, and am authorized to apply for its withholding on behalf of NuScale

(2) I am knowledgeable of the criteria and procedures used by NuScale in designating information as a trade secret, privileged, or as confidential commercial or financial information. This request to withhold information from public disclosure is driven by one or more of the following:

(a) The information requested to be withheld reveals distinguishing aspects of a process (or component, structure, tool, method, etc.) whose use by NuScale competitors, without a license from NuScale, would constitute a competitive economic disadvantage to NuScale.

(b) The information requested to be withheld consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), and the application of the data secures a competitive economic advantage, as described more fully in paragraph 3 of this Affidavit.

(c) Use by a competitor of the information requested to be withheld would reduce the competitor's expenditure of resources, or improve its competitive position, in the design, manufacture, shipment, installation, assurance of quality, or licensing of a similar product.

(d) The information requested to be withheld reveals cost or price information, production capabilities, budget levels, or commercial strategies of NuScale.

(e) The information requested to be withheld consists of patentable ideas.

(3) Public disclosure of the information sought to be withheld is likely to cause substantial harm to NuScale's competitive position and foreclose or reduce the availability of profit-making opportunities. The accompanying report reveals distinguishing aspects about the process by which NuScale develops its statistical subchannel analysis methodology.

NuScale has performed significant research and evaluation to develop a basis for this methodology and has invested significant resources, including the expenditure of a considerable sum of money.

The precise financial value of the information is difficult to quantify, but it is a key element of the design basis for a NuScale plant and, therefore, has substantial value to NuScale.

If the information were disclosed to the public, NuScale's competitors would have access to the information without purchasing the right to use it or having been required to undertake a similar expenditure of resources. Such disclosure would constitute a misappropriation of NuScale's intellectual property, and would deprive NuScale of the opportunity to exercise its competitive advantage to seek an adequate return on its investment.

(4) The information sought to be withheld is in Enclosure 1 to the Approved version of "Statistical Subchannel Analysis Methodology Supplement 1 to TR-0915-17564-P-A, Revision 2, Subchannel Analysis Methodology," TR-108601-P-A, Revision 4. The enclosure contains the designation "Proprietary" at the top of each page containing proprietary information. The information considered by NuScale to be proprietary is identified within double braces, "{{ }}" in the document.

(5) The basis for proposing that the information be withheld is that NuScale treats the information as a trade secret, privileged, or as confidential commercial or financial information. NuScale relies upon

the exemption from disclosure set forth in the Freedom of Information Act ("FOIA"), 5 USC § 552(b)(4), as well as exemptions applicable to the NRC under 10 CFR §§ 2.390(a)(4) and 9.17(a)(4).

(6) Pursuant to the provisions set forth in 10 CFR § 2.390(b)(4), the following is provided for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld:

(a) The information sought to be withheld is owned and has been held in confidence by NuScale.

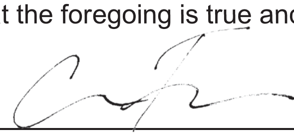
(b) The information is of a sort customarily held in confidence by NuScale and, to the best of my knowledge and belief, consistently has been held in confidence by NuScale. The procedure for approval of external release of such information typically requires review by the staff manager, project manager, chief technology officer or other equivalent authority, or the manager of the cognizant marketing function (or his delegate), for technical content, competitive effect, and determination of the accuracy of the proprietary designation. Disclosures outside NuScale are limited to regulatory bodies, customers and potential customers and their agents, suppliers, licensees, and others with a legitimate need for the information, and then only in accordance with appropriate regulatory provisions or contractual agreements to maintain confidentiality.

(c) The information is being transmitted to and received by the NRC in confidence.

(d) No public disclosure of the information has been made, and it is not available in public sources. All disclosures to third parties, including any required transmittals to NRC, have been made, or must be made, pursuant to regulatory provisions or contractual agreements that provide for maintenance of the information in confidence.

(e) Public disclosure of the information is likely to cause substantial harm to the competitive position of NuScale, taking into account the value of the information to NuScale, the amount of effort and money expended by NuScale in developing the information, and the difficulty others would have in acquiring or duplicating the information. The information sought to be withheld is part of NuScale's technology that provides NuScale with a competitive advantage over other firms in the industry. NuScale has invested significant human and financial capital in developing this technology and NuScale believes it would be difficult for others to duplicate the technology without access to the information sought to be withheld.

I declare under penalty of perjury that the foregoing is true and correct. Executed on April 15, 2024.



Carrie Fosaaen