April 28, 2023 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, “Applicability Range Extension of NSP4 Critical Heat Flux Correlation, Supplement 1 to TR-0116-21012-P-A, Revision 1,” TR-107522, Revision 1

REFERENCES:
1. NRC Letter to NuScale, “Final Safety Evaluation for NuScale TR-107522, Revision 0, ‘Applicability Range Extension of NSP4 Critical Heat Flux Correlation’ (Prop/Non Prop),” dated April 12, 2023 (ML23065A003)
2. Letter from NuScale to NRC, “Applicability Range Extension of NSP4 Critical Heat Flux Correlation, Supplement 1 to TR-0116-21012-P-A, Revision 1, TR-107522, Revision 1,” dated October 27, 2022 (ML22300A244)

By referenced letter dated April 12, 2023 (Reference 1), the NRC issued a final safety evaluation report documenting the NRC Staff conclusion that the NuScale topical report “Applicability Range Extension of NSP4 Critical Heat Flux Correlation, Supplement 1 to TR-0116-21012-P-A, Revision 1,” TR-107522, Revision 1 (Reference 2), 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-107522, Revision 1, within three months of receipt of the letter.

Enclosure 1 contains the proprietary version of the report entitled “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. NuScale requests that the proprietary version be withheld from public disclosure in accordance with the requirements of 10 CFR § 2.390. The enclosed affidavits (Enclosure 3 and 4) support 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 3 pertains to the NuScale proprietary information, denoted by double braces (i.e., “{{ }}”). Enclosure 4 pertains to the Framatome Inc. (formerly AREVA Inc.) proprietary information, denoted by brackets (i.e., “[ ]”). Enclosure 2 contains the nonproprietary version of the report.

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.

Sincerely,

Mark W. Shaver
Acting Director, Regulatory Affairs
NuScale Power, LLC

Distribution: Michael Dudek, NRC
Getachew Tesfaye, NRC
Bruce Bavol, NRC

Enclosure 1: "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, proprietary version
Enclosure 2: "Applicability Range Extension of NSP4 Critical Heat Flux Correlation, Supplement 1 to TR-0116-21012-P-A, Revision 1," TR-107522-NP-A, Revision 1, nonproprietary version
Enclosure 3: Affidavit of Mark W. Shaver, AF-138877
Enclosure 4: Affidavit of Morris Byram, Framatome

Enclosure 1:

"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, proprietary version

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Enclosure 2:

"Applicability Range Extension of NSP4 Critical Heat Flux Correlation, Supplement 1 to TR-0116-21012-P-A, Revision 1," TR-107522-NP-A, Revision 1, nonproprietary version

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Contents

Section A

From:	Bruce Bavol
To:	Regulatory Affairs
Cc:	Michael Dudek; Getachew Tesfaye; Stacy Joseph; Griffith, Thomas; Fowler, Wren
Subject:	Final Safety Evaluation for NuScale TR-107522, Revision 0, “Applicability Range Extension of NSP4 Critical Heat Flux Correlation" (Prop/Non Prop)
Date:	Wednesday, April 12, 2023 5:10:58 AM
Attachments:	NuScale_TR 107522 Rev 1 CHF.pdf NuScale_TR 107522 Rev 1 CHF_Non Prop.pdf

By letter dated November 5, 2021, NuScale Power, LLC (NuScale), submitted Topical Report supplement (TR)-107522, Revision 0, “Applicability Range Extension of NSP4 Critical Heat Flux Correlation: Supplement 1 to TR-0116-21012-P-A, Revision 1,” (Agencywide Documents Access and Management System (ADAMS) Accession No. ML21309A753 - package). Additional supplemental data tables were sent by letter dated January 14, 2022, (ML22014A248) - which will be included as Appendix A to the referenced TR. By letter dated October 27, 2022, (ML22300A244 and ML22300A243), NuScale submitted TR-107522, Revision 1, to the U.S. Nuclear Regulatory Commission (NRC) which updated the TR supplement text to include the latest information. The NRC staff has found that TR-107522, Revision 1, 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 enclosed final safety evaluation. The password protected proprietary/export control information version and the non-proprietary version of the safety evaluation has been attached. A separate email will be sent with the password.

NOTE: Because of the significant number of additional redactions to the SER, I have password protected both the public and non-public versions. Please take one more look to verify the redactions of the public version. Staff accepted the NuScale edits. There were several comments were staff left as is.

The NRC staff requests that NuScale submit the approved version of this TR within three months of receipt of this electronic mail. The approved 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 responses. The approved version of the TR shall include an “-A” (designated approved) following the report identification number.

If the NRC’s criteria or regulations change such that the NRC staff’s conclusion in this electronic mail 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 at (301) 415-6715 or via e-mail address at Bruce.Bavol@nrc.gov.

Sincerely,

Bruce M. Bavol

Project Manager
Office of Nuclear Reactor Regulation
DNRL/NRLB

Docket No. 99902078

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

SUPPLEMENT 1 TO TR-0116-21012-P-A

TOPICAL REPORT 107522, REVISION 1

"APPLICABILITY RANGE EXTENSION OF NSP4 CRITICAL HEAT FLUX CORRELATION"

NUSCALE POWER, LLC

EPID NO. [EPID NO. L-2021-TOP-0033]

1.0 INTRODUCTION

By letter dated November 5, 2021 (Reference 1), NuScale Power, LLC (NuScale) submitted a request for review and approval of Topical Report (TR)-107522, Revision 0, “Applicability Range Extension of NSP4 Critical Heat Flux Correlation: Supplement 1 to TR-0116-21012-P-A, Revision 1,” to the U.S. Nuclear Regulatory Commission (NRC). By letter dated October 27, 2022 (Reference 16), NuScale submitted TR-107522, Revision 1, “Applicability Range Extension of NSP4 Critical Heat Flux Correlation,” to NRC that incorporates the requested updates from staff. The purpose of this report was to provide the bases for an extension to the range of applicability for the NSP4 critical heat flux (CHF) model[1] to be used for the safety analysis of the NuScale Power Module (NPM) with NuFuel-HTP2™ fuel. The range of applicability is expanded to ensure the NSP4 model encompasses the operating domain of the NPM at higher rated power levels.

The complete list of correspondence between the NRC staff and NuScale is provided in Table 1 below which contains the correspondence relevant to this review.

Table 1: List of Key Correspondence

Sender	Document	Document Date	Reference
NuScale	Topical Report – Supplement 1	November 5, 2021	1
NRC staff	Request for Supplemental Information	December 1, 2021	3
NuScale	Supplementary Information to Topical Report	January 14, 2022	4
NuScale	CHF Notes and Slides	February 18, 2022	5
NRC staff	Request for Additional Information (eRAI 9899)	March 30, 2022	6
NuScale	Response to eRAI 9899	July 20, 2022	7
NRC staff	Request for Additional Supplemental Information (eRAI 9899)	September 8, 2022	8
NuScale	Supplemental Response to eRAI 9899	September 30, 2022	9
NuScale	Revision 1 to TR-107522	October 27, 2022	16

In performing this review, the NRC staff applied a credibility assessment framework which focused on critical boiling transition (CBT)[2] models. The framework is fully described throughout the safety evaluation (SE).

[1] The terms “model” and “correlation” are synonymous. While this SE primarily uses the word “model”, there is no difference between a CHF correlation and a CHF model.
[2] CBT is the name given to the phenomena which occur when a flow regime that has a higher heat transfer rate transitions to a flow regime that has a significantly lower heat transfer rate. Historically, terms such as CHF, departure from nucleate boiling, and critical power have been used. However, the NRC staff needed a way to separate the general phenomena occurring (i.e., CBT) from a specific type of phenomena which may occur (e.g., departure from nucleate boiling, dryout) and from the specific values of certain parameters which are often used to signify that such a transition has occurred (e.g., CHF, critical power).

2.0 <u>REGULATORY EVALUATION</u>

General Design Criterion (GDC) 10 of Title 10 *Code of Federal Regulation*s (10 CFR) Part 50, 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 are not exceeded during any condition of normal operation, including the effects of anticipated operational occurrences.” GDC 12 states, “The reactor core and associated coolant, control, and protection systems shall be designed to assure that power oscillations which can result in conditions exceeding specified acceptable fuel design limits are not possible or can be reliably and readily detected and suppressed.” Thus, GDC 10 and 12 introduce the concept of specified acceptable fuel design limits (SAFDLs).

In essence, SAFDLs are those limits placed on certain variables to ensure that the fuel does not fail. One such SAFDL is associated with CBT. CBT is defined as a transition from a boiling flow regime that has a higher heat transfer rate to a flow regime that has a significantly lower heat transfer rate. If the reduction in the heat transfer rate and resulting increase in surface temperature is large enough, the surface may weaken or melt. In a nuclear power plant, this condition could result in fuel damage.

In order to ensure that such a CBT does not occur, SAFDLs have been developed, as described in Standard Review Plan, Section 4.4, Thermal and Hydraulic Design (Reference 10). For NuScale, one SAFDL has been proposed as an acceptable means for satisfying GDC 10 and 12 as documented in Section 4.4 of its Design-Specific Review Standard (Reference 15).

(A) For CHF correlations, 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 anticipated operational occurrences (AOOs).

Therefore, the main objective of the NRC Staff’s review was to determine if the NSP4 model could result in accurate predictions, such that there would be a 95-percent probability at the 95-percent confidence level that the hot rod in the core does not experience CBT during normal operation or AOOs.

3.0 TECHNICAL EVALUATION

The purpose of TR-107522, "Applicability Range Extension of NSP4 Critical Heat Flux Correlation: Supplement 1 to TR-0116-21012-P-A, Revision 1" (Reference 1 and 16), is to provide the bases for an extension to the range of applicability for the NSP4 model to be used for the safety analysis of the NPM with NuFuel-HTP2™ fuel. The NRC staff's technical evaluation focused on determining if the model is acceptable for use in reactor safety license calculations (i.e., that the model can be trusted) for the extended range.

To perform this evaluation, the NRC staff used a framework similar to the framework used in the NRC staff's SE of the original NuScale Power CHF model (Reference 2). More details about the framework applied in this review can be found in NUREG/KM-0013 (Reference 12). Note that many of the findings are based on the initial review performed on the original submittal, TR-0116-21012-P-A, "Critical Heat Flux Correlations," (Reference 2), which TR-107522 supplements.

The review framework is generated from a single main goal; then that main goal is logically decomposed into subgoals. Logical decomposition is the process of generating a set of subgoals which are logically equivalent (i.e., necessary and sufficient) to the main goal. This decomposition is expressed using Goal Structure Notation. Each subgoal can either be further logically decomposed into other subgoals or if no further decomposition is deemed useful, the subgoal is considered a base goal and evidence must be provided to demonstrate that the base goal is true.

For CBT models, the top goal is: *The CBT model can be trusted in reactor safety analyses.* Based on the engineering judgement and experience from multiple NRC technical staff members and a study of previous SEs, this goal is decomposed into various subgoals as given in the figures below, starting with the decomposition of the main goal into the three subgoals given in Figure 1.

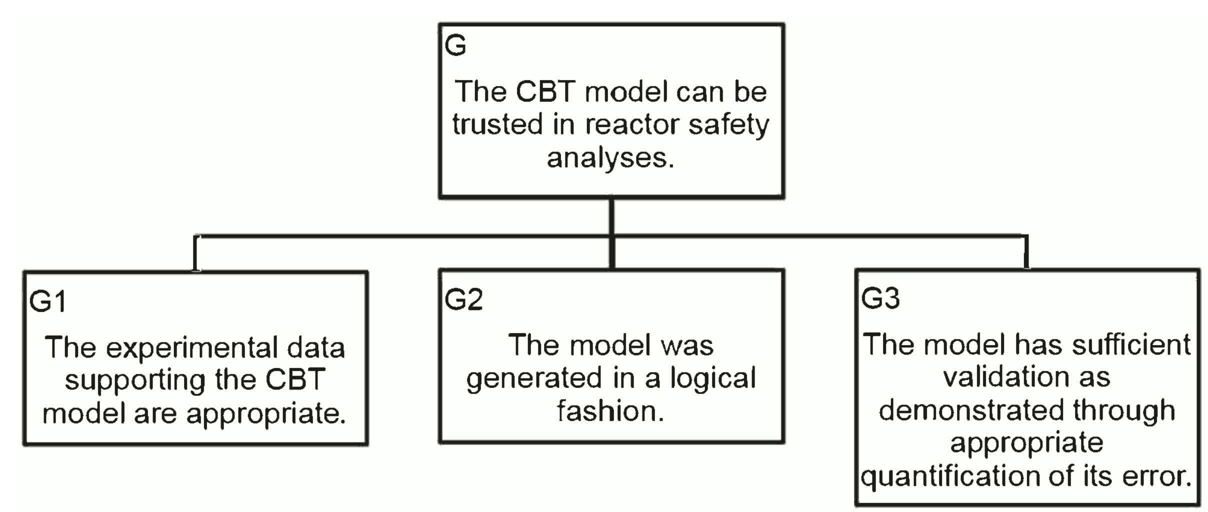

Figure 1: Decomposition of G – Main Goal

The NSP4 model has already been approved by the NRC, and therefore the NRC staff has previously considered these three goals to have been met. The expansion of the range of applicability for the NSP4 model would not impact the NRC staff's findings on G1 and G2, as those are independent of the application domain in which the model is applied. For the NSP4 model, the only exception within these subgoals is the subgoal related to equivalent grid spacers and this is addressed below. The expansion of the range of applicability would impact G3 so the NRC staff focused its review in this supplement on ensuring that the validation of the NSP4 model did not change with the extended range of applicability.

3.1 Experimental Data

Experimental data is the cornerstone of a CBT model. Not only is the data used to generate the coefficients of the model and validate the model, but previous data are often used to generate the model's form. Therefore, it is essential that the experimental data are appropriate. Demonstrating that the experimental data are appropriate is accomplished using the three subgoals given in Figure 2 below.

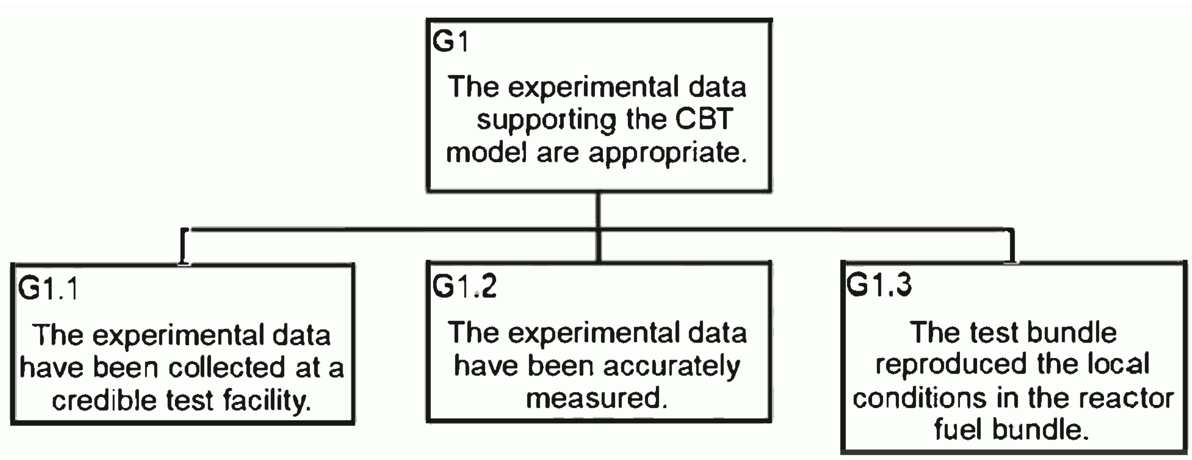

Figure 2: Decomposing G1 – Experimental Data

As stated above, the NSP4 model has already been approved, and therefore the NRC staff has previously considered these three goals to have been met. The expansion of the range of applicability for the NSP4 model would not impact the NRC staff's findings on G1.1 and G1.2, as both the Stern and Kathy experimental facilities have been determined to be credible test facilities and it has previously been determined that this data has been accurately measured. Therefore, the subgoals G1.1 and G1.2 are considered satisfied through the staff's review documented in Reference 2, and only G1.3 was further investigated in the staff's review in this supplement.

3.1.1 Reproduced Local Conditions

The next subgoal in demonstrating that the experimental data are appropriate is to demonstrate that the local conditions in the reactor have been reproduced in the experiment. This is typically demonstrated using the five subgoals as given in Figure 3 below.

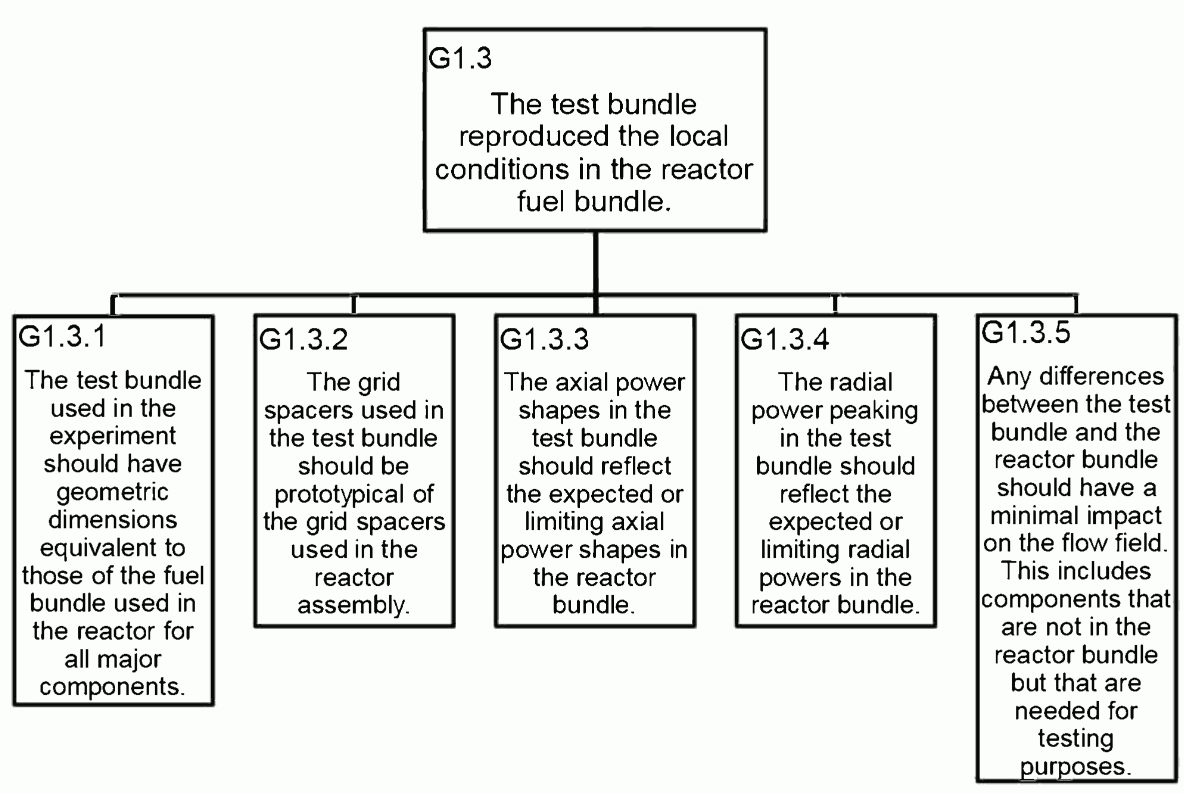

Figure 3: Decomposing G1.3 – Reproduced Local Conditions

The NSP4 model has already been approved in Reference 2, and therefore the NRC staff has previously considered all of these goals to have been met. This expansion of the range of applicability for the NSP4 model would not impact the NRC staff's findings on G1.3.1, G1.3.3, G1.3.4, and G1.3.5 and these subgoals are considered to have been met in the prior review of the NSP4 model. However, the NRC staff decided to re-evaluate subgoal G1.3.2 again for this review as there is a difference in the grid spacers used in the Stern data (which supports the range extension) and the grid spacer used in NuFuel-HTP2™ fuel. Therefore, only this goal is evaluated below.

3.1.1.1 *Equivalent Grid Spacers*

> **Equivalent Grid Spacers**
>
> *The grid spacers used in the test bundle should be prototypical of the grid spacers used in the reactor assembly.*
>
> G1.3.2, Review Framework for CBT Models

The primary source of data for the range extension is the high mass flux data from Stern. As described in the original CHF TR (Reference 2), NuFuel-HTP2™ contains five grid spacers, the bottom of which is an HMP spacer and the top four being HTP spacers. However, the data from Stern are based on "simple grids," that is grid spacers which were primarily designed to ensure the fuel rods maintain their distance from other fuel rods and not designed to increase flow mixing. All grid spacers induced some flow mixing downstream of the spacer which evens out the qualities and enthalpies in the subchannels of the fuel assembly resulting in more margin to CHF. That is, if the grid spacers were removed, CHF would occur much sooner. While even simple grids provide some benefit, additional benefit can be gained if the grid spacer is specifically designed to induce mixing. Depending on the amount of mixing and the grid spacer design, the increase in CHF margin varies, but a 10%-20% increase in CHF margin would be expected.

It is common to use CHF data from simple grids and mixing grids to generate and validate a CHF model. Moreover, using a model developed on grid spacers with simple grids has been previously considered by the NRC staff to be conservative for predicting the performance of fuel with mixing vanes (Reference 11). However, this is different from what NuScale is requesting in this supplement.

To that point, instead of using the data from simple grids as a conservative prediction of CHF performance, NuScale used the data from simple grids to validate the NSP4 model. The main challenge with this approach is that the NSP4 model was developed for mixing grids, not simple grids. Thus, the staff expected the model to over-predict the CHF performance of the simple grids in the Stern tests as the NSP4 model is based on mixing grid data. The staff determined that the amount of the over-prediction varies, based on the magnitude of mixing in the grid spacers which were used to generate the data for the NSP4 model.

The NSP4 model is primarily based on fuel with HTP grids. HTP grids are a unique design in that they do not contain mixing vanes. Instead, the grid spacers contain flow channels built into the grid spacer whose purpose is to mix the flow. While all mixing vane designs are proprietary and the mixing performance is difficult to quantify, in the NRC staff's experience, the HTP grids were not primarily designed to increase CHF performance. While the grids do increase CHF margin, this margin increase is not as great as other grids which were designed primarily to increase that margin. Thus, it is the staff view that the NSP4 model's over-prediction of the CHF performance of simple grids (such as those used in the Stern test) would not be as great as the over-prediction produced by a typical mixing vane CHF model's analysis of those same simple grids.

Additionally, the distance between the grid spacers on NuFuel-HTP2™ is approximately **{{[ ]}}**∗, while the grid spacers of the Stern assemblies was **{{ }}**. Generally, in the staff's view, applying CHF data from a longer span between grid spacers (e.g., the Stern data) to a shorter span (e.g., the NuFuel-HTP2™ fuel) is considered conservative as CHF performance of the assembly with the longer span would be expected to be worse than of the assembly with the shorter span.

Even though there is a difference between the grid spacers used in the development of the range extension and those of the NuFuel-HTP2™ assembly, the NRC staff finds that the grid spacers used in the test bundle are appropriate even though they are not prototypical as there is reasonable assurance that the CHF data obtained from Stern can be conservatively applied to the NuFuel-HTP2™. That is, the staff finds there is reasonable assurance that the NuFuel-HTP2™ assembly will have better CHF performance than that measured from the bundle tested at the Stern facility. The NRC staff concludes that this goal (G1.3.2) has been met.

∗ {{[ ]}} - Information Considered Proprietary to Framatome

3.2 Model Validation

Validation is the accumulation of evidence which is used to assess the claim that a model can predict a real physical quantity (Reference 13). Thus, validation is a never-ending process as more evidence can always be obtained to bolster this claim. However, at some point, when the accumulation of evidence is considered sufficient to make a judgment that the model can be trusted for its given purpose, the model is said to be validated. Demonstrating the model validation is appropriate is accomplished using the five subgoals given in Figure 4 below.

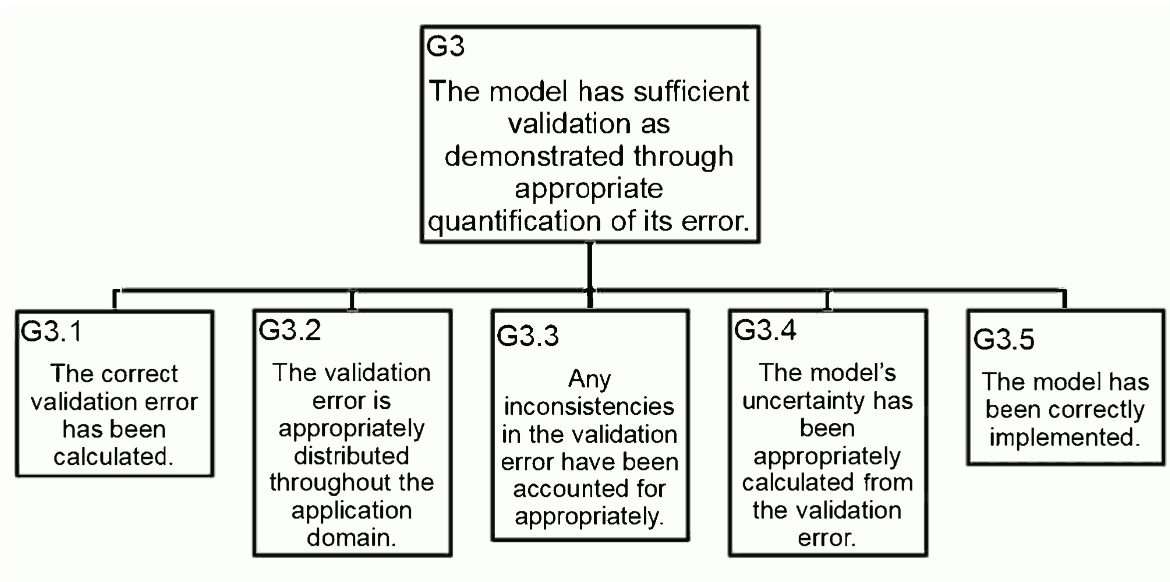

Figure 4: Decomposing G3 – Model Validation

3.2.1 Validation Error

Validation Error
The correct validation error has been calculated.
G3.1, Review Framework for CBT Models

The validation error is obtained from a ratio of the predicted CHF value and the measured CHF value, which is consistent with the method used to determine the validation error in the original TR (Reference 2). Because NuScale is using the same validation error in this supplement, the NRC staff finds that the correct error has been calculated. The NRC staff concludes that this goal has been met.

3.2.2 Data Distribution

The second subgoal in demonstrating that the model's validation was appropriate is to demonstrate that the data is appropriately distributed throughout the application domain. This is typically demonstrated using the six subgoals as given in Figure 5 below.

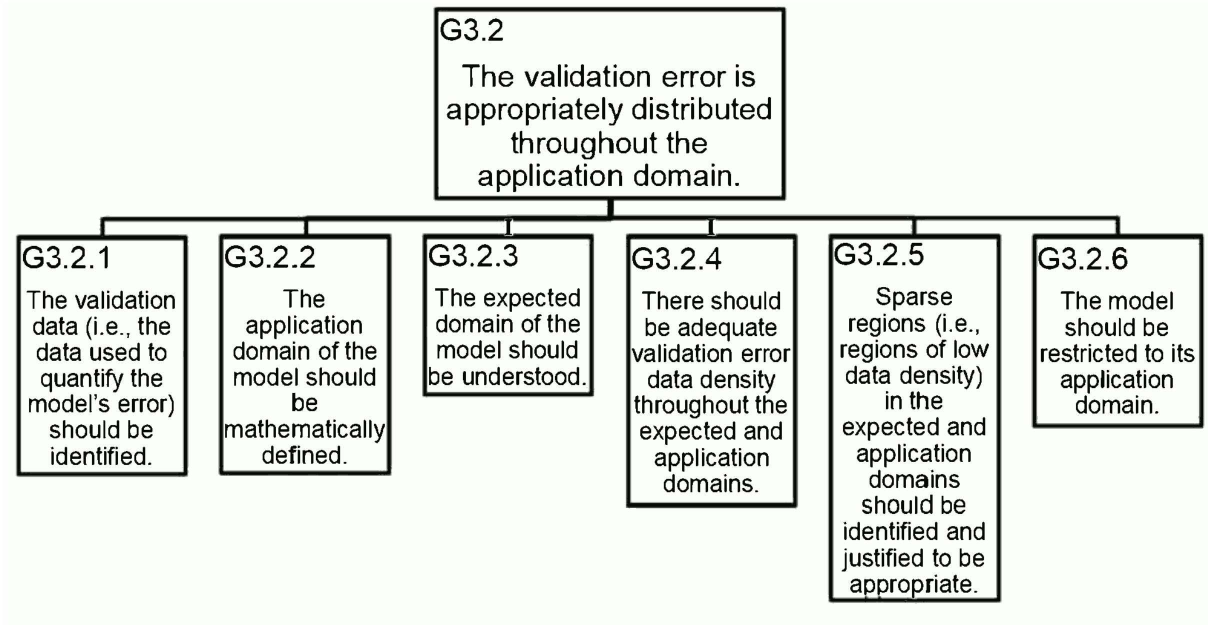

Figure 5: Decomposing G3.2 – Data Distribution

The evidence the staff considered in determining whether the goals were met is provided below.

3.2.2.1 *Validation Data*

Validation Data
The validation data (i.e., the data used to quantify the model's error) should be identified.
G3.2.1, Review Framework for CBT Models

NuScale identified the validation data for the extension to the NSP4 model as the data taken from the Stern facility. Therefore, the NRC staff concludes that this goal has been met.

3.2.2.2 *Application Domain*

Application Domain
The application domain of the model should be mathematically defined.
G3.2.2, Review Framework for CBT Models

NuScale identified the application domain of the NSP4 model in Table 8-4 of the original topical (Reference 2). In its initial request (Reference 1 and 16), NuScale requested an extension of the upper mass flux limit from 0.635 (Mlbm/hr-ft^2) to 0.7000 in Table 5-1. In a later RAI response (Reference 7), NuScale increased the value in this Table 5-1 to 0.7500. This safety evaluation is focusing on the this increase in the application domain from 0.6350 to 0.7500 (Mlbm/hr-ft^2).

Because this applicability domain is defined in Table 5-1, the NRC staff concludes that this goal has been met.

3.2.2.3 *Expected Domain*

Expected Domain

The expected domain of the model should be understood.

G3.2.3, Review Framework for CBT Models

The expected domain of the NSP4 model has not been further defined from the application domain. The expected domain is a useful construct which enables reviewers to better focus on specific areas of the application domain where the use of the given CHF model is expected. However, given the small increase in the application domain due to the addition of the extended mass flux range, the benefit of defining a separate expected domain is limited. Therefore, the entire application domain will be used as the expected domain. Because the expected domain is not defined separately from that application domain and is only used to further focus on the review on regions of the application domain in which the use of NSP4 model would be expected, the NRC staff has concluded that this criterion does not apply.

3.2.2.4 *Data Density*

Data Density

There should be an appropriate data density throughout the expected domain.

G3.2.4, Review Framework for CBT Models

To understand the data density, the NRC staff created plots (Figures 6-11) demonstrating the data density of the initial NSP4 model (Reference 2) along with data in the extended domain. The primary data supporting the validation of the NSP4 model is from tests K8500 (Kathy data) and tests U1 and U2 (Stern data). These tests were not used in the initial approval of the NSP4 model. Additionally, the NRC staff did consider predictions of test C1, but did not believe it was reasonable to include this data in the validation analysis for reasons discussed in Section 3.2.3.1 of this SE.

To determine the data density, the staff created 2D plots of the **{{**

}} These plots were used by the staff to confirm that the density of the validation was sufficient in the application domain.

First, the staff plotted the original data for the approved NSP4 model (o – black circle). This data is an example of a reasonable data density over the application domain that the staff previously found to be acceptable in Reference 2. Second, the staff plotted the NSP4 data from tests K8500, U1, and U2 in the currently approved mass flux range (□ – blue square). Finally, the staff plotted the NSP4 data from tests K8500, U1, and U2 in the extended mass flux range (x – red ‘x’), that is data above a mass flux of 0.635 (Mlbm/hr-ft^2). A summary of these data is provided in Table 2.

Table 2: Legend for Data Density Plots

Original NSP4 data	o
Current Mass Flux Range	□
Extended Mass Flux Range	x

Because the staff was evaluating a four-dimensional application domain (pressure, mass flux, local quality, and inlet subcooling), the staff created six plots to compare each dimension with each other. The data density plots are given in Figure 6 through Figure 11 below.

Figures 6, 7, 8, 9, 10, and 11
{{[

]}}

Based on the data density displayed Figure 6 – Figure 11, the NRC staff considers that there is no significant difference between the data density of the original NSP4 model and the data density in the extended mass flux domain. Because there is no significant difference, the NRC staff concludes that this goal has been met.

3.2.2.5 *Sparse Regions*

Sparse Regions
Sparse regions (i.e., regions of low data density) in the expected domain should be identified and justified to be appropriate.
G3.2.5, Review Framework for CBT Models

Based on the review Figure 6 – Figure 11, the NRC staff was not able to identify any sparse regions. The NRC staff therefore concludes that this goal has been met.

3.2.2.6 *Restricted Domain*

Restricted Domain
The model should be restricted to its application domain.
G3.2.6, Review Framework for CBT Models

The staff already concluded in the original NSP4 SE (Reference 2) that NuScale appropriately restricted the NSP4 model to its application domain. Because this TR supplement would only modify that domain, the NRC staff finds that the change in the upper mass flux limit would not necessitate a new review of this goal. The NRC staff therefore concludes that the restricted domain goal has been met.

3.2.3 Consistent Model Error

The third subgoal in demonstrating that the model's validation was appropriate is to demonstrate that the model error is consistent over the application domain. This is typically demonstrated using the three subgoals as given in Figure 12 below.

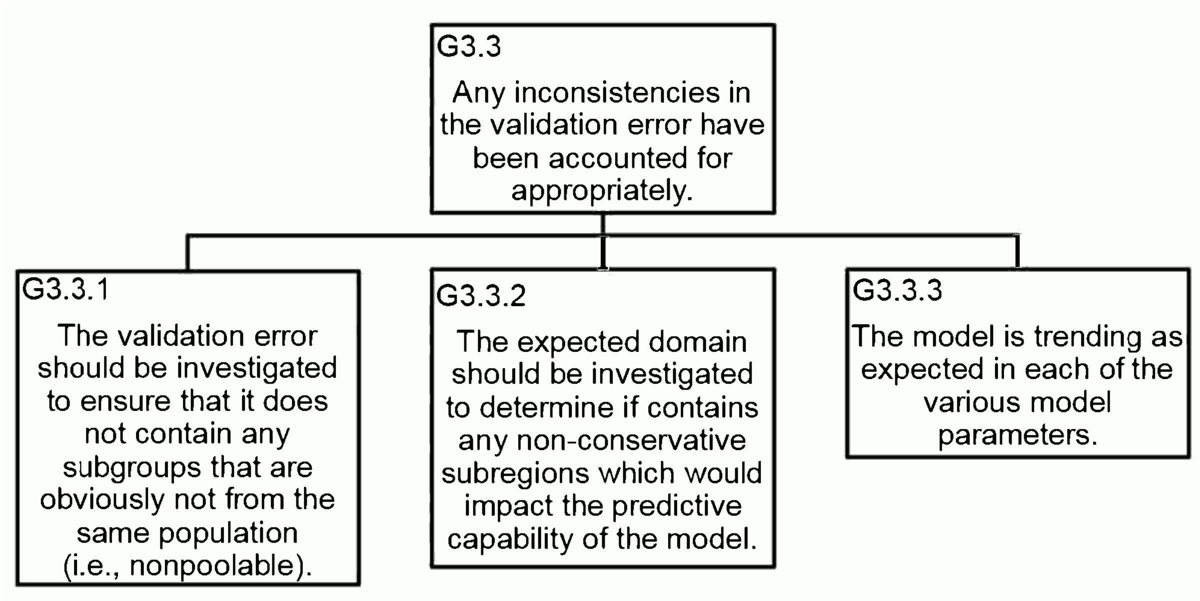

Figure 12: Decomposing G3.3 – Consistent Model Error

The evidence demonstrating that the following goals were met is provided below.

3.2.3.1 *Poolability*

> **Poolability**
>
> *The validation error should be investigated to determine if it contains any subgroups which are obviously not from the same population (i.e., not poolable).*
>
> G3.3.1, Review Framework for CBT Models

Figure 4-3 of the TR supplement (Reference 1 and 16) provides the predicted to measured (P/M) CHF values for three different tests as a function of mass flux. Tests U1 and U2 have a uniform power shape while test C1 has a cosine power shape. In the **{{ }}**, the cosine test is predicted very conservatively[3], while the uniform tests have some conservative and some non-conservative predictions. For the uniform tests, of the **{{ }}** in the high mass flux region, **{{ }}** exceeded the requested departure from nucleate boiling ratio (DNBR) limit of 1.21 while **{{ }}** of the cosine tests exceeded the 95/95 (or even a P/M value of 1.0).

In response to RAI 9899, NTR-02 (Reference 7) NuScale provided further justification for the few non-conservative predictions. First, it reiterated that the tests of U1 and U2 contained simple grid spacers, while the NSP4 model is based on mixing vane grids. Based on this explanation, the staff would expect that a model which has been trained on mixing vane data

[3] For P/M plots, a prediction is said to be conservative when the P/M value is less than 1.0. This means that that the CHF has been measured at higher heat flux than the model predicts. Likewise, a prediction is said to be non-conservative when the P/M value is greater than 1.0. This means that that the CHF has been measured at lower heat flux than the model predicts. Generally, only non-conservative predictions above the DNBR limit are a concern.

would be non-conservative in predicting simple grid tests as that model would predict better CHF performance than would be expected for the simple grids.

As a demonstration of the consistency of the NSP4 model's prediction of simple grid data, NuScale pointed to Region 2 of Figure 4-1. The NSP4 model has been approved in this region with a DNBR limit of 1.21 (Reference 2). However, the NSP4 model's predictions of U1 and U2 in **{{** **}}**. Thus, in response to RAI 9899, NTR-02 NuScale stated that it is reasonable to assume that the non-conservative behavior is due entirely to using the NSP4 model to predict the simple grid data, and **{{** **}}**. NuScale also discussed the conservative trend in mass flux is likely due to **{{** **}}**.

In general, the NRC staff would expect a model such as NSP4 to non-conservatively predict simple grid data. Thus, the trends in Figure 4-3 are not surprising. In further assessing the validity of the model, the NRC staff investigated both **{{** **}}** to determine if there was any reason to believe that the same DNBR limit of 1.21 which was approved for **{{** **}}**. This included an investigation into the very conservative prediction of the cosine data from test C1.

One of the first items the staff noted was the inability of the NSP4 model to correctly predict the elevation of CHF. The elevation error for tests C1, U1 and U2 (% difference between the location predicted and location measured) is given in Figure 13, Figure 14, and Figure 15 below.
{{

}}

Figure 13: Elevation Error vs. Local Mass Flux for Test C1

For tests C1, the NSP4 model predicts CHF to occur at a much different elevation than where CHF was measured. Because test C1 has a cosine power shape, this incorrect prediction not only impacts the "predicted" value from the correlation, but also the "measured" value from the test. The "measured" and "predicted" location is determined from the subchannel which has the minimum DNBR (i.e., the subchannel which is believed to be closest to experiencing CHF). For uniform power shapes, the heat flux of all channels is the same. Thus the "measured" heat flux is the same irrespective of which subchannel has the minimum DNBR. However, for cosine power shapes, the heat flux peaks at the center and falls off at the edges, thus the "measured" CHF will vary depending on the subchannel which is predicted to the have the minimum DNBR. One concern as demonstrated in Figure 13 is that while the NSP4 model does predict conservatively, **{{**

}} The NRC staff was concerned about if this trend **{{** **}}**. Further, the staff was concerned that if the trend **{{** **}}**.

Because of the large differences between the "measured" CHF values and local conditions used in the analysis of the C1 test data compared to the actual CHF values and local conditions at which CHF occurred in the test, the NRC staff does not believe that the C1 tests demonstrate that the NSP4 model would accurately or conservatively predict CHF. While the analysis does show that the NSP4 model conservatively predicted test C1, the NRC staff does not believe it is reasonable to expect the model to have the same performance in the reactor and cannot determine if the reactor performance would be more or less conservative. However, the NRC staff does not believe that the prediction of the C1 invalidates the NSP4 model, as it does not provide any evidence that the model would behave in a non-conservative manner. Therefore, as discussed in Section 3.2.4.3, the NRC staff relied on other data to determine the acceptability of the NSP4 model in the extended mass flux region.

{{

}}

Figure 14: Elevation Error vs. Local Mass Flux for Test U1

{{

}}

Figure 15: Elevation Error vs. Local Mass Flux for Test U2

For tests U1 and U2, the NRC staff found that the NSP4 model does a good job of predicting the elevation of CHF at lower mass flux conditions. While predicting the exact elevation is not a requirement, being able to predict the elevation is often used as further evidence that the model is behaving as expected. For tests with a uniform axial power shape, CHF should always occur at the end of the heated length. This is because the end of the heated length will have the highest quality, highest enthalpy, and highest void at the exit. In one sense, looking axially down a test section could be considered looking "back" in time, as the local conditions at lower elevations should have been "experienced" at the very end of the heated length first. This analogy breaks down just above the spacer grids where there is significant turbulent mixing, but it holds for just below the spacer grid spacers where CHF generally occurs.

The staff noted that, in the high mass flux region, the NSP4 model predicts CHF to occur **{{ }}** based on previous staff experience. **{{ }}** To better understand this behavior, the NRC staff performed an analysis similar to that of NuScale and considered the contribution of each term in the NSP4 model to the final predicted value of CHF. The model is given in Equation 7-1 of the initial TR (Reference 2) and is restated below for convenience.

{{ }}

In order to investigate the behavior of this model, the NRC staff considered the value of each term and how much that term contributed to the final sum of all terms. **{{**

[4].}} The staff evaluated the model[5] by examining the contribution of each term in Eq. 7-1. The contribution of each term for the U1 and U2 tests is given in Figure 16.

{{

}}

Figure 16: Contribution of each term in NSP4

Figure 16 displays the percent contribution of each of the **{{** **}}**. To better understand this plot, consider the first group of data at low mass fluxes (around 0.1). The "red triangle" (△) represents **{{** **}}**. The "yellow star" (✳) represents **{{** **}}**.

Figure 16 provides insight into the mechanics of the NSP4 model, as it visually displays which terms are important in the prediction of CHF and if those terms are acting to increase or decrease the predicted CHF value. For the extended mass flux range currently under review (i.e., mass fluxes greater than 0.635), **{{**

{{[4] **}}**

[5] In order to perform this evaluation, the NRC staff recreated the NSP4 correlation in MATLAB. While the correlation form is easy to program and NuScale provided all of the data for the necessary inputs, the staff's version of NSP4 correlation varied slightly (usually within 5%) from the predicted CHF value reported by NuScale. The staff considers that this variation is reasonable for the given analysis.

}}. To demonstrate this better, a zoomed in view of the high mass flux region is given in Figure 17.

{{

}}

Figure 17: Contribution of each term in NSP4 (High Hass Flux Region)

A comparison of Figure 16 and Figure 17 demonstrates that the behavior of the NSP4 model is **{{** **}}**. For example, **{{** **}}**

From this analysis, the NRC staff concludes that while the same NSP4 model would be used at higher mass fluxes, **{{** **}}** as demonstrated in Figure 16. Thus, this is not a simple extension, **{{** **}}**. Similar to the NSP4 model's inability to predict the correct elevation of CHF in test C1, this analysis does not provide any evidence that the model would behave in a non-conservative manner.

In response to RAI 9899, NTR-02, NuScale stated that **{{** **}}**. However, the NRC staff disagrees with this conclusion. The NRC staff found that the results from the above analysis demonstrate that there is a **{{**

}} and the staff therefore concluded that these two datasets should not be pooled together.

In summary, the NRC staff has concluded that that there was not a sufficient justification to pool the data from the **{{**

}} However, the NRC staff has concluded that similar behavior of the **{{**

}} inside the extended mass flux range to determine the appropriate DNBR limit in that range. Based on this analysis of the poolability of the different data sets, the NRC staff has determined that this goal has been met.

3.2.3.2 *Non-Conservative Subregions*

> **Non-Conservative Subregions**
>
> The expected domain should be investigated to determine if contains any non-conservative subregions which would impact the predictive capability of the model.
>
> G3.3.2, Review Framework for CBT Models

The staff investigated the domain for non-conservative subregions and **{{**
}}. For this analysis, **{{**

}} The non-conservative behavior as a function of **{{**
}} can be seen in Figure 18 which shows the P/M values as a function of **{{** **}}**.

{{[

]}}

Figure 18: {{ }} for U1, U2, and K8500 (view 1)

Because it is often hard to interpret a 3-D plot on paper, the staff prepared Figure 19 using the same data but with a rotated view.

{{[

]}}

Figure 19: {{ }} for U1, U2, and K8500 (view 2)

Finally, this 3-D data is collapsed by ignoring the **{{ }}** value in Figure 20.

{{[

]}}

Figure 20: {{ }} for U1, U2, and K8500

Figure 20 illustrates that there is a substantial non-conservative increase in the P/M values for **{{ }}**. That increase is not observed in the K8500 test. Since K8500 is also a simple grid test, the staff considers it unlikely that the increase is due to the “over-prediction” of **{{ }}**. If this were the primary reason, the same “non-conservative” prediction would be seen in K8500, and while K8500 is **{{ }}** the DNBR limit of 1.21), the **{{ }}**.

From Figure 18 and Figure 19, the staff observed that the **{{ }}**. This can be seen when comparing the **{{ }}** value as given in Figure 21.

{{[

]]}}

Figure 21: {{ }} for U1, U2, and K8500

As illustrated in Figure 21, the **{{** **}}**. From this analysis, the NRC staff concludes that while there seems to be a non-conservative subregion in the extended mass flux domain, that subregion is **{{** **}}**. That non-conservative subregion is addressed in Section 3.2.4.3, "*Appropriate Bias for Model Uncertainty*," below. With the exception of the non-conservative subregion **{{** **}}**, the NRC staff did not identify any other non-conservative subregions. Because the expected domain has been investigated for non-conservative subregions, the NRC staff concludes that this goal has been met.

3.2.3.3 *Model Trends*

> **Model Trends**
>
> *The model is trending as expected in each of the various model parameters.*
>
> G3.3.3, Review Framework for CBT Models

Due to the limited nature of the review for the mass flux extension from 0.635 to a mass flux of 0.75, the NRC staff did not specifically review all model trends, but instead focused on those trends related to the P/M values as discussed elsewhere in this safety evaluation. The NRC staff concludes that this criterion has been addressed elsewhere in this SE in the analysis of poolability (3.2.3.1 *Poolability*), the analysis of non-conservative subregions (3.2.3.2 *Non-Conservative Subregions*), and the determination of the DNBR limit (3.2.4.3 *Appropriate Bias for Model Uncertainty*).

3.2.4 Quantified Model Error

The fourth subgoal in demonstrating that the model's validation was appropriate is to demonstrate that the model error has been appropriately quantified over the application domain. This is typically demonstrated using the three subgoals as given in Figure 22 below.

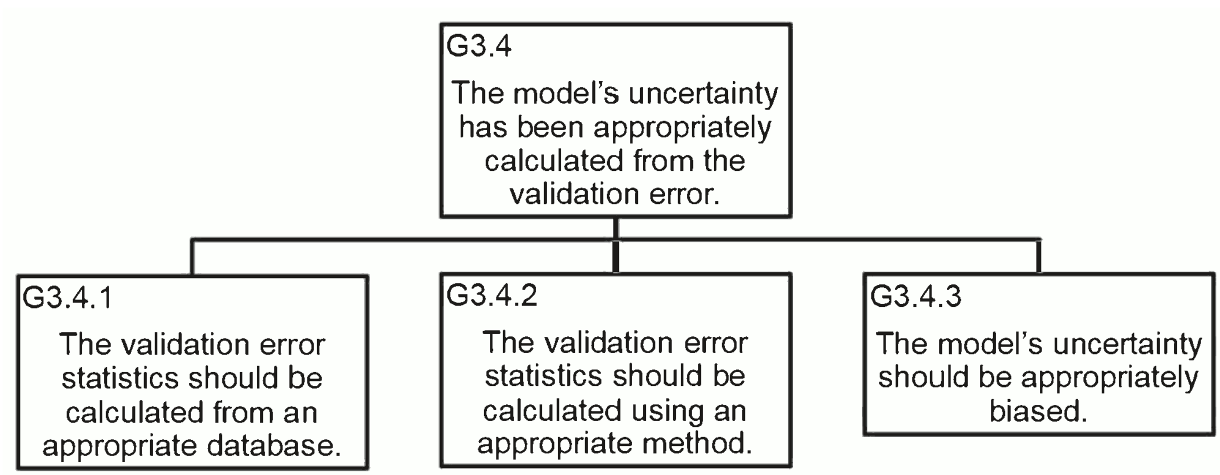

Figure 22: Decomposing G3.4 – Quantified Model Error

The evidence demonstrating the following goals were met is provided below.

3.2.4.1 *Error Data Base*

Error Data Base
The validation error statistics should be calculated from an appropriate database.
G3.4.1, Review Framework for CBT Models

The applicant determined the validation error by comparing the predictions of the NSP4 model to data from specific experiments. However, during the review NuScale informed the NRC staff (References 7 and 8) that it had removed specific data points from the analysis because those data points were outside the requested range of application. Further, while some of the removed data points were discussed in the TR and its supplement, others were not. In general, the NRC staff considers that data driven models such as CHF models, should have all "reasonably available" data provided, and if such data is not provided or not used in the analysis, then it should be made clear to the reviewer what data is not being used and why.

In the staff's experience, it is common for applicants to disposition specific test runs from various tests and not use the data for a variety of reasons. However, deciding that the data can be ignored is a decision that often relies on engineering judgment, and such judgments are reviewed by the NRC staff and are necessary for making an assessment on the validation of the model. This is because the data ignored may provide evidence that the model's predictive capability is much lower than anticipated. This has been captured in a recommendation in the staff's SE for future reviewers.

The NRC staff has determined that these data were appropriate for validation as the data were not used to train the NSP4 model, therefore, the NRC staff considers that this goal has been met.

3.2.4.2 *Statistical Method*

Statistical Method

The validation error statistics should be calculated using an appropriate method.

G3.4.2, Review Framework for CBT Models

Due to the complexities of the validation data (i.e., because the NSP4 model is a mixing vane model, it will non-conservatively predict the CHF performance of a simple grid), the staff could not perform a statistical comparison which demonstrates that the model's prediction in the extended mass flux region is bounded by the DNBR limit of 1.21. Because a statistical comparison could not be performed, the NRC staff concludes that this criterion does not apply in this review and therefore engineering judgment must be utilized to ensure that there is reasonable assurance that the DNBR limit used in the high mass flux region will satisfy the 95/95 departure from nucleate boiling (DNB) criterion. The justification for the DNBR limit in the extended mass flux region is described in Section 3.2.4.3 *Appropriate Bias for Model Uncertainty*.

3.2.4.3 *Appropriate Bias for Model Uncertainty*

Appropriate Bias

The model's error should be appropriately biased in generating the model uncertainty.

G3.4.3, Review Framework for CBT Models

In response to RAI 9899, NTR-02 (Reference 7), NuScale provided additional justification for applying the DNBR limit of 1.21 to the extended mass flux range. NuScale also provided additional justification in section 4.1 and Table 4-2 in Rev 1 of the TR. In general, the NRC staff agrees with much of this analysis, as confirmed by the staff's own analysis. **{{**

}} Both of these are demonstrated in Figure 21 of this SE. However, the NRC staff disagrees with the conclusions drawn by NuScale that the DNBR limit of 1.21 would satisfy the 95/95 criterion in the high mass flux domain, for the reasons described below.

While the staff does expect to see non-conservative predictions of the U1, U2, and K8500 tests because those tests had simple grids, while the NSP4 model used mixing grids, the magnitude of the non-conservative predictions of the U1 and U2 tests seems to be too high. From Figure 20 of this SE, the staff notes the impact of using the NSP4 model to predict simple grids in the **{{**

}} to be fully attributed to the fact that the data is from simple grids.

Figure 20 of this SE illustrates that this non-conservatism is **{{** **}}**. Therefore, the staff determined that the bias should be separated into a **{{** **}}**. The **{{** **}}** was chosen based on the staff's conservative engineering judgment, as the data below this pressure (including K8500 test data and U1 and U2 data) demonstrated similar predictive capability. The validation of the NSP4 model for **{{** **}}** is given in Figure 23.

{{[

]}}

Figure 23: Mass Flux vs P/M for U1, U2, and K8500 {{ }}

The NRC staff determined that there was not enough data from tests U1, U2, and K8500 to determine the 95/95 in the high mass flux region. The data point which had the most non-conservative prediction has a P/M value of **{{ }}**, and while this value is above the DNBR limit of 1.21, it is within the **{{ }}**. However, the NRC staff had the following concerns for the extended mass flux region:

(a) The staff was concerned about the epistemic uncertainty associated with the lack of sufficient data to demonstrate compliance with the DNBR limit of 1.21 in the extended mass flux domain. **{{ }}**, this value is not a reasonable estimate of the 95/95 given the limited number of data points in the region. The NRC staff would expect the 95/95 value to **{{ }}**.

(b) The staff was concerned about the epistemic uncertainty associated with the unknown impact of the NSP4 model's consistent prediction of CHF at much lower elevations than measured. While the NSP4 model's predictions of the U1 and U2 tests in the extended mass flux range were reasonable, the staff was concerned because the model's predictions (including those predictions of the C1 tests) **{{**

}}

(c) The staff was concerned about the epistemic uncertainty associated with unknown impact in predictive capability resulting from the shift in the **{{**

}} in the extended mass flux domain, the NRC staff believed that it was reasonable to assume that the NSP4 model's predictive capability would be changed in that domain.

(d) The staff was concerned about the lack of representative data for the NuFuel-HTP2™ fuel and the non-conservative P/M predictions in the extended mass flux domain. While simple grid CHF data has been used previously to demonstrate the conservative nature of a mixing-grid CHF model, the model generally conservatively predicts the data. That is not the case for the NSP4 model, as the NRC staff had to determine the degree of non-conservatism expected due to using the mixing-vane correlation on simple grid fuel. While the NRC staff and NuScale did perform an analysis to determine this non-conservatism, the NRC staff notes that this is not a common analysis and believes there may be uncertainties which have not been addressed.

Based on concerns (a) – (d) above, the NRC staff's previous experience with CHF models, and the NRC staff's conservative engineering judgment, the NRC staff concludes that a penalty of **{{**

}} of the extended mass flux domain. This is reflected in condition and Limitation 1 as stated; For mass fluxes greater than **{{**

}}

The validation of the NSP4 model for **{{** **}}** is given in Figure 24.

{{[

]}}

Figure 24: Mass Flux vs P/M for U1, U2, and K8500 {{ }}

Like the **{{ }}**, there is not enough data from tests U1, U2, and K8500 to determine the 95/95 in the **{{ }}**. **{{ }}** Further, as demonstrated in Figure 24 above, the P/M value of **{{ }}** is not an outlier as there are multiple values which are close to this value in the high mass flux domain.

Based on concerns (a) – (d) above, on the few P/M values at **{{ }}** and their non-conservative values which exceed the safety limit of 1.21 and **{{ }}**, the NRC staff's previous experience with CHF models, and the NRC staff's conservative engineering judgment, **{{ }}**. This is reflected in condition and Limitation 2 as stated; For mass fluxes greater than **{{ }}**

Based on the staff's analysis and application of the penalties as condition and Limitations 1 and 2 of this SE, the NRC staff concludes that, subject to the satisfaction of these conditions and limitations, the goal of applying an appropriate bias for model uncertainty has been met.

3.2.5 Model Implementation

The fifth subgoal in demonstrating that the model's validation was appropriate is to demonstrate that the model will be implemented in a manner consistent with its validation. This is typically demonstrated using the two subgoals as given in Figure 25 below.

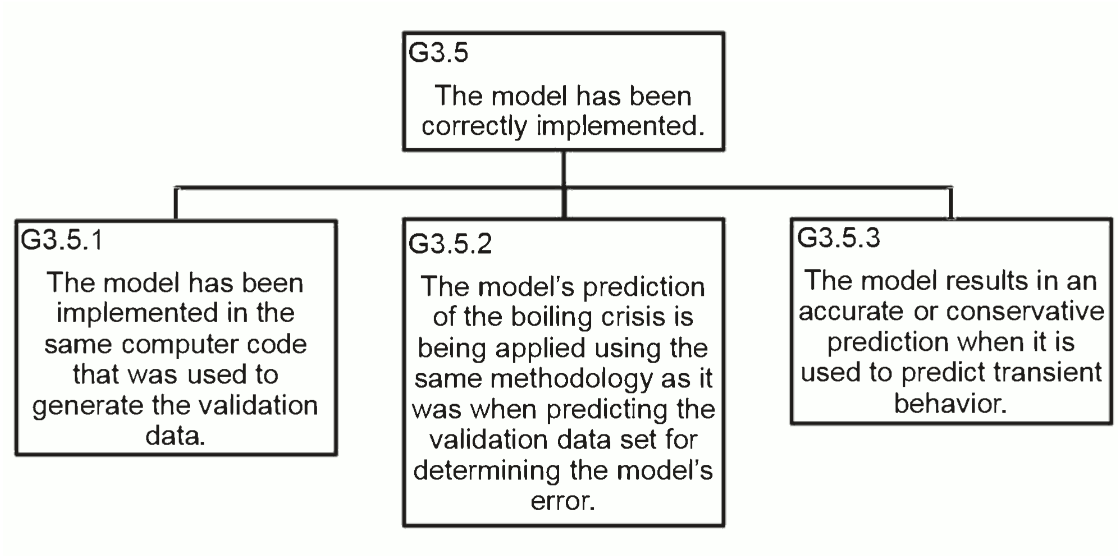

Figure 25: Decomposing G3.5 – Model Implementation

The evidence demonstrating the following goals were met is provided below.

3.2.5.1 *Same Computer Code*

> **Same Computer Code**
>
> *The model has been implemented in the same computer code which was used to generate the validation data.*
>
> G3.5.1, Review Framework for CBT Models

Sections 3.3.1 and 3.3.2 in the original TR-0116-21012 (Reference 2) show that the VIPRE-01 models are used by NuScale to perform the data reduction calculations in accordance with TR-0915-17594, "Subchannel Analysis Methodology" (Reference 14). To ensure that the NSP4 model is used in a manner consistent with its validation, in the NRC staff's original SE the staff established Limitation 2 on the use of VIPRE-01 calculations using the NSP4 model. Based on the description in Sections 3.3.1 and 3.3.2 of the original TR, and pursuant to Limitation 2, the NRC staff found that the NSP4 model is implemented using the same computer code used to generate the validation data.

3.2.5.2 *Same Methodology*

Same Methodology
The model's prediction of the CBT is being applied using the same methodology as it was when predicting the validation data set for determining the validation error.
G3.5.2, Review Framework for CBT Models

As described in Section 3.1.3.5.1 of this SE, the NRC staff established Limitation 2 in the original SE to ensure that the NSP4 model is used in a manner consistent with its validation. Based on the description in Sections 3.3.1 and 3.3.2 of the original NRC-approved TR-0116-21012-P-A (Reference 2), and pursuant to Limitation 2, the NRC staff found that the NSP4 model is being applied in the same manner as when predicting the validation data set.

3.2.5.3 *Transient Prediction*

Transient Prediction
The model results in an accurate or conservative prediction when it is used to predict transient behavior.
G3.5.3, Review Framework for CBT Models

The focus of this review was to determine the DNBR limit for an extension in the mass flux range. Because this increase in mass flux range would not impact the use of this model's ability to predict transient behavior, the NRC staff has determined that this goal does not apply.

4.0 CONCLUSION

Based on the NRC staff's review in Section 3.2 of this SE, the NRC staff concludes that the NSP4 model has sufficient validation in the extended mass flux region up to a mass flux of 0.7500 (Mlbm/hr-ft^2) as demonstrated through appropriate quantification of its error. Therefore, the NRC staff concludes that the NSP4 model can be relied upon in reactor safety analyses such as determining whether the SAFDL (as defined in GDC 10 and 12 of 10 CFR Part 50, Appendix A) of DNBR satisfies the criterion for CHF correlations. Further, 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, as provided in the NuScale Design-Specific Review Criteria (Reference 15). The staff's conclusion is subject to the conditions and limitations listed below.

4.1 Conditions and Limitations

The following conditions and limitations must be met to apply the NSP4 model in the extended mass flux range.

1. For mass fluxes greater than **{{**

   }}

2. For mass fluxes greater than **{{**

   }}

3. The NSP4 model is limited to mass fluxes below 0.7500 (Mlbm/hr-ft^2). The full application domain is given in Table 5-1 of the TR.

4. The application of the NSP4 model is limited to type NuFuel-HTP2^{TM} fuel.

5. Any application deviation from the modeling options or deviation from the use of the subchannel code which was used to perform this validation assessment would require re-validation similar to the validation provided in the TR and would require NRC review and approval. Any application to a new fuel type or new mixing vane spacer type, any decrease in the CHF design limits, or any expansion of the application domain would require NRC review and approval.

4.2 Staff Recommendations

The following recommendation is made for NRC staff reviews of future supplements to or revision of this TR:

1. The NRC staff believes that data driven models such as CHF models should have all "reasonably available" data provided, and if such data are not provided or not used in the analysis, then it should be made clear to the reviewer what data are not being used and why. The NRC staff should ensure that there is reasonable justification for ignoring any such data when performing the validation of such a data driven model.

5.0 REFERENCES

1. NuScale Power, LLC, "Applicability Range Extension of NSP4 Critical Heat Flux Correlation: Supplement 1 to TR-0116-21012-P-A, Revision 1," TR-107522, Revision 0, November 2021, ADAMS Accession Nos. ML21309A755 (*Proprietary Version)* and ML21309A754 (*Non-Proprietary*).

2. NuScale Power, LLC, "Critical Heat Flux Correlations," TR-0116-21012-P-A, Revision 1, December 19, 2018, ADAMS Accession No. ADAMS Accession No. ML18360A633 and ML18360A634 (*Proprietary Version*) and ML18360A632 (*Nonproprietary Version*).

3. Email from Bruce Bavol (NRC) to Rebecca Norris (NuScale), "TR-107522 NuScale Supplement to CHF," dated December 1, 2021. (ADAMS Accession No. ML22020A030).

4. NuScale Power, LLC, "Submittal of Supplementary Information to Topical Report Entitled 'Applicability Range Extension of NSP4 Critical Heat Flux Correlation: Supplement 1 to TR-0116-21012-P-A, Revision 1,'" TR-107522, January 14, 2022, ADAMS Accession No. ML22014A249 (*Proprietary Version*) and ML22014A248 (*Nonproprietary Version*).

5. NuScale Power, LLC, "Submittal of Supplementary Information to Topical Report "Applicability Range Extension of NSP4 Critical Heat Flux Correlation: Supplement 1 to TR-0116-21012-P-A, Revision 1," TR-107522, Revision 0," LO-114135, February 18, 2022, ADAMS Accession No. ML22049A790 (*Proprietary Version*) and ML22049A789 (*Nonproprietary Version*).

6. Final Request for Information eRAI 9899, dated March 30, 2022 ADAMS Accession No. ML22089A024 (Nonproprietary Version). ADAMS Accession No. ML22089A023 (*Proprietary Version*).

7. NuScale Power, LLC, "NuScale Power, LLC Response to NRC Request for Additional Information (RAI No. 9899) on the NuScale Topical Report, "Applicability Range Extension of NSP4 CHF Correlation," TR-107522, Revision 0," July 20, 2022, ADAMS Accession No. ML22201A533 (*Proprietary Version*) and ML22201A532 (*Nonproprietary Version*).

8. Email from Bruce Bavol (NRC) to Thomas Griffith (NuScale), "NuScale TR-107522, Revision 0, "Critical Heat Flux Correlation," dated September 8, 2022 ADAMS Accession No. ML22251A391(*Nonproprietary Version*). ADAMS Accession No. ML22251A380 (*Proprietary Version*).

9. NuScale Power, LLC, "NuScale Power, LLC Supplemental Response to NRC Request for Additional Information (RAI No. 9899) on the NuScale Topical Report, "Critical Heat Flux," TR-0116-21012, Revision 1-A", September 30, 2022, ADAMS Accession No. ML22273A169 (*Proprietary Version*) and ML22273A168 (*Nonproprietary Version*).

10. U.S. Nuclear Regulatory Commission, “Thermal and Hydraulic Design,” Section 4.4 of NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition,” Revision 2, March 2007, ADAMS Accession No. ML070550060.

11. Morey, D. C., U.S. Nuclear Regulatory Commission, letter to Gary Peters, Framatome Inc., “Final Safety Evaluation for Framatome Inc. Topical Report ANP-10341P, ‘The ORFEO-GAIA and ORFEO-NMGRID Critical Heat Flux Correlations’ (CAC No. MF8400; EPID L-2016-TOP-0008),” dated September 24, 2018 (ADAMS Accession No. ML18236A371).

12. Kaizer, J.S., Anzalone, A., Brown, E., Panicker, M., Haider, S., Gilmer, J., Drzewiecki, T., and A. Attard, "Credibility Assessment Framework for Boiling Crisis Transition Models,” NUREG/KM-0013-DRAFT, 2018.

13. Oberkampf, W.L., and C.J. Roy, *Verification and Validation in Scientific Computing*, Cambridge University Press, Cambridge, United Kingdom, 2010.

14. NuScale Power, LLC, “Subchannel Analysis Methodology,” TR-0915-17564-P-A, Revision 2, March 19, 2019, ADAMS Accession No. ADAMS Accession No. ML19067A257 and ML19067A258 (*Proprietary Version*) and ML19067A256 (*Nonproprietary Version*).

15. U.S. Nuclear Regulatory Commission, “Thermal and Hydraulic Design,” Section 4.4 of “Design-Specific Review Standard for NuScale SMR Design,” June 17, 2016, ADAMS Accession No. ML15355A468.

16. NuScale Power, LLC, “Applicability Range Extension of NSP4 Critical Heat Flux Correlation: Supplement 1 to TR-0116-21012-P-A, Revision 1,” TR-107522, Revision 1, October 2022, ADAMS Accession Nos. ML22300A244 (*Proprietary Version)*) and ML22300A243 (*Non-Proprietary*).

6.0 LIST OF ACRONYMS

AOO	anticipated operational occurrence
CBT	critical boiling transition
CFR	*Code of Federal Regulations*
CHF	critical heat flux
DNB	departure from nucleate boiling
DNBR	departure from nucleate boiling ratio
NPM	NuScale Power Module
NRC	U.S. Nuclear Regulatory Commission
NuScale	NuScale Power, LLC
SAFDL	specified acceptable fuel design limit
SE	safety evaluation
TR	topical report

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Section B

Licensing Topical Report

Applicability Range Extension of NSP4 Critical Heat Flux Correlation

Supplement 1 to TR-0116-21012-P-A, Revision 1, NuScale Power Critical Heat Flux Correlations

April 2023

Revision 1

Docket: 99902078

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List of Affected Pages

Revision Number	Page Number	Explanation
0	All	Initial Issue
1	All	Revised to address NRC Requests for Additional Information 9899

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Abstract

The purpose of this topical report supplement is to provide the bases for Nuclear Regulatory Commission approval of an extension to the range of applicability in Tables 7-5 and 8-4 for the NSP4 critical heat flux (CHF) approved in topical report TR-0116-21012-P-A, Revision 1, “NuScale Power Critical Heat Flux Correlations.” The correlation and correlation limit justified and approved in the topical report remain unchanged.

Executive Summary

The purpose of this report is to provide the bases for Nuclear Regulatory Commission approval to use the NSP4 CHF correlation in VIPRE-01, within its expanded range of applicability in Table 5-1, along with its associated correlation limit 1.21, for the NuScale safety analysis of the NPM with NuFuel-HTP2™ fuel.

This correlation conforms to acceptance criteria given by the NuScale Design-Specific Review Standard (DSRS) and the requirements of 10 CFR 50, Appendix A, General Design Criterion (GDC) 10.

The method of justification {{

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

1.0 Introduction

1.1 Purpose

The applicable range of the NSP4 CHF correlation contained in TR-0116-21012-P-A, Revision 1 (Reference 6.1.1) was adequate for the NuScale Power Module (NPM) described in the Design Certification Approval (DCA). The range of applicability is expanded to ensure the NSP4 CHF correlation encompasses the operating domain of the NPM at higher rated power levels.

1.2 Scope

This supplement provides justification for extending the applicable range of the mass flux for the NSP4 critical heat flux (CHF) correlation (Reference 6.1.1).This supplement will assess the available CHF data, and justify an extension to the mass flux applicability range for the NSP4 critical heat flux correlation, while retaining the approved correlation limit of 1.21 for safety analysis evaluations of the NPM with NuFuel-HTP2™ fuel.

The numbering of Section 1 through 3 in this document follows that of TR-0116-21012-P-A, Revision 1 in order to assist the reader in relating this supplement to the original topical report. Section 4 provides a description of the evaluation and assessment that justifies the expanded applicability. Section 5 provides a summary of the results, along with the updated applicability range for the NSP4 CHF correlation. Appendix A provides the local thermal-hydraulic parameters for each of the evaluated test series with the NSP4 correlation.

1.3 Abbreviations and Definitions

This section is unchanged relative to the corresponding section of Reference 6.1.1.

2.0 Background

The NuScale topical report TR-0116-21012-P-A, Revision 1, “NuScale Power Critical heat Flux Correlations,” presents the NSP2 and NSP4 critical heat flux (CHF) correlations that have been developed by NuScale to assess CHF performance for normal operation, anticipated operational occurrences (AOOs), and postulated accidents in the NuScale Power Module (NPM) with NuFuel-HTP2™ fuel. In particular, the NRC found the NSP4 CHF correlation acceptable for use in performing safety analyses of the NPM with NuFuel-HTP-2™ fuel, with its associated correlation limit 1.21, over the range of applicability provided in Table 8-4 of TR-0116-21012-P-A, Revision 1.

2.1 Regulatory Requirements

This section is unchanged relative to the corresponding section of Reference 6.1.1.

2.2 NuScale Power Module Fuel Assembly Design

This section is unchanged relative to the corresponding section of Reference 6.1.1.

3.0 Analysis and Experimentation

This section is unchanged relative to the corresponding section of Reference 6.1.1.

4.0 Extension of Mass Flux Range for NSP4 Critical Heat Flux Correlation

The method of justification {{

}}2(a),(c)

4.1 Stern CHF Data Evaluation

The Stern CHF database covers a much wider range of mass flux as shown in Reference 6.1.1, Table A-1. This data more than adequately covers the extended upper limit of mass flux desired in the NSP4 CHF correlation. The test assemblies for the Stern CHF tests (Reference 6.1.1, Table 3-2) are similar to the NuFuel-HTP2™ design (Reference 6.1.1, Tables 3-6, 3-7, 3-8, and 3-10) as illustrated in Table 4-1. The fuel rod pitch and outer diameter, guide tube diameter, and heated length are all identical between the two. The only difference lies with the spacer grids. Where NuFuel-HTP2™ uses a combination of Framatome HMP™ and HTP™ spacer grids that have built-in mixing features, the grids in Stern testing {{

}}2(a),(c) with NSP4 because the NSP4 CHF correlation is based on the HMP™ and HTP™ spacer grids. However, as pointed out in Reference 6.1.1; Section 3.1.2, "… *at low flows, such as those of the NPM, any mixing benefits provided by the HTP™ design decrease.*" So, the difference in grid spacer type is not expected to significantly affect results {{

}}2(a),(c) In addition, the spacer grid span is {{ }}2(a),(c) for the Stern tests than in the NuFuel-HTP2™ design. This difference is small enough that it will not affect results since there is no variable in the NSP4 CHF correlation accounting for grid span. Therefore, using Stern CHF data to support the justification of increasing the upper mass flux limit of the NSP4 CHF correlation is acceptable.

Table 4-1 Geometry Comparison Between NuFuel-HTP2™ and Stern Test Assemblies

Parameter	NuFuel-HTP2™	Stern	Difference
Fuel rod pitch (in.)	0.496	0.496	0.0%
Fuel rod outer diameter (in.)	0.374	0.374	0.0%
Guide tube outer diameter (in.)	0.482	0.482	0.0%
Heated length (in.)	78.74	78.74	0.0%
Spacer grid type	HMP™/HTP™	{{ }}2(a),(c)	-
Spacer grid span (in.)	{{ [ ]		}}2(a),(c),ECI

Critical heat flux values are calculated for the Stern test local conditions (Reference 6.1.1, Table A-1) with the NSP4 CHF correlation using VIPRE-01. All VIPRE-01 inputs, including two-phase correlations and mixing coefficients, are used in a manner consistent with the approved NSP4 CHF correlation topical report.

Limiting CHF values (i.e., the CHF at the location of minimum CHFR) are used to form a population. {{

}}2(a),(c) because this is below the lower limit of the NSP4 CHF correlation applicability range. The {{

}}2(a),(c)

The population is divided into three sub-populations:

- {{

}}2(a),(c)

The predicted-to-measured ratios for these sub-populations are plotted versus mass flux in Figure 4-1. From this figure, it is observed that these three sub-regions occur naturally based on visual trends of P/M versus mass flux. Predicted-to-measured comparison for {{ }}2(a),(c) and generally trend towards more conservative predictions (i.e., lower P/M ratios) than the rest of the data. The general trend in the predicted-to-measured plot in Figure 4-2 {{

}}2(a),(c)

Table 4-2 Stern NSP4 Statistical Figure-of-Merits

Parameter	{{		
Mean			
Standard Deviation			
Non-parametric Bound			
Parametric Bound			
Mean			
Standard Deviation			
Non-parametric Bound			
Parametric Bound			
Mean			
Standard Deviation			
Non-parametric Bound			
Parametric Bound			}}2(a),(c)

{{

}}2(a),(c)

Figure 4-1 Stern Test P/M Versus Local Mass Flux Values at Minimum CHFR Location

{{

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

Figure 4-2 Stern Test Predicted Versus Measured Local Heat Flux Values

{{

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

5.0 Summary and Conclusions

The upper end of the mass flux range for NSP4 CHF correlation is extended to a value of 0.75 Mlbm/hr·ft². The range extension is validated by using data from a separate CHF test program that contains data ranges greater {{ }}2(a),(c)

Local condition data from {{ }}2(a),(c) are generated using VIPRE-01 with the NSP4 CHF correlation. The measured and predicted values are compared and show that the {{ }}2(a),(c) which demonstrates the NSP4 design limit for the approved domain conservatively bounds the extended domain to 0.75 Mlbm/(hr-ft^2).

The use of the NSP4 CHF correlation to an upper bound 0.75 Mlbm/(hr-ft^2) is validated and appropriate. The extended applicability range for the NSP4 CHF correlation is shown in Table 5-1.

Table 5-1 NSP4 CHF Correlation Extended Applicability Ranges

Parameter	Units	Lower Limit	Upper Limit
Pressure	psia	500	2,300
Mass flux	Mlbm/hr·ft²	0.110	0.750
Local quality	-	n/a	95%
Inlet quality	-	n/a	0%

6.0 References

6.1 Referenced Documents

6.1.1 NuScale Power, LLC, "NuScale Power Critical Heat Flux Correlations," TR-0116-21012-P-A, Revision 1.

6.1.2 U.S. Nuclear Regulatory Commission, "Applying Statistics," NUREG-1475, Revision 1, March 2011.

Appendix A Local Conditions

This appendix provides tabulated parameters for Stern test series U1, U2, and C1 evaluated with the NSP4 CHF correlation.

Definitions:

TEST	Test identifier
POINT	Test point
Z_{pred}	Elevation of CHF prediction from bottom of heated length, in.
P	Pressure, psia
G_{in}	Approximate inlet mass flux (test matrix value), Mlbm/(hr-ft^2)
ΔT_{sub}	Approximate inlet subcooling (test matrix value), °F
G	Local mass flux, Mlbm/hr-ft^2
X	Local equilibrium quality
Z_{boil}	Boiling length {{ }}2(a),(c)

{{ }}2(a),(c)

{{ }}2(a),(c)

$q''_{pred}(I_{chf})$	Predicted CHF, MBtu/hr-ft^2
F-factor	Modified Tong F-factor
P/M	Predicted-to-measured CHF ratio

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Section C

RAI Number	eRAI Number	NuScale Letter Number
9899	NTR-01 NTR-02	RAIO-118038, Enclosure 2
9899	NTR-01S1	RAIO-126873, Enclosure 2

NUSCALE
Power for all humankind

RAIO-118038

July 20, 2022

Docket: 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 Response to NRC Request for Additional Information (RAI No. 9899) on the NuScale Topical Report, "Applicability Range Extension of NSP4 CHF Correlation," TR-107522, Revision 0

REFERENCES:
1. NRC Letter Final Request for Information eRAI 9899 (Proprietary), dated March 14, 2022, RAI# 9899
2. NuScale Topical Report Applicability Range Extension of NSP4 CHF Correlation, dated January 2022, TR-107522

The purpose of this letter is to provide NuScale's response to NRC Requests for Additional Information (RAI), RAI# 9899, noted in the References above. The responses to the individual RAI questions are provided in the attached Enclosures.

This letter contains NuScale's response to the following RAI Questions from NRC RAI# 9899:

- NTR-01
- NTR-02

Enclosure 1 is the proprietary version of NuScale's response to RAI #9899. Enclosure 2 is the non-proprietary version of NuScale's response to RAI #9899. NuScale requests that the proprietary version be withheld from public disclosure in accordance with the requirements of 10 CFR § 2.390. The enclosed affidavits (Enclosure 3 and 4) support this request. Enclosure 3 pertains to the NuScale proprietary information, denoted by double braces (i.e., “{{ }}”). Enclosure 4 pertains to the Framatome Inc. proprietary information, denoted by brackets (i.e., “[ ]”). Enclosure 2 contains the nonproprietary version of the report.

Enclosures are grouped with all proprietary version responses first, followed by all nonproprietary version responses. NuScale requests that the proprietary version be withheld from public disclosure in accordance with the requirements of 10 CFR § 2.390. The enclosed affidavit supports this request. The proprietary enclosures have been deemed to contain Export Controlled Information. This information must be protected from disclosure per the requirements of 10 CFR § 810.

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

Please contact Thomas Griffith at 541-452-7813 or at tgriffith@nuscalepower.com if you have any questions.

Sincerely,

Mark W. Shaver

Mark Shaver
Manager, Licensing
NuScale Power, LLC

Distribution: Bruce Bavol, NRC
Getachew Tesfaye, NRC
Michael Dudek, NRC

Enclosure 1: NuScale Response to NRC Request for Additional Information RAI# 9899, proprietary

Enclosure 2: NuScale Response to NRC Request for Additional Information RAI# 9899, nonproprietary

Enclosure 3: Affidavit of Mark Shaver, AF-118039
Enclosure 4: Affidavit of Morris Byram, Framatome Inc. AF-117384

Enclosure 2:

NuScale Response to NRC Request for Additional Information eRAI No. 9899, nonproprietary

Response to Request for Additional Information
Docket: 99902078

RAI No.: 9899
Date of RAI Issue: 03/21/2022

NRC Question No.: NTR-01

Regulatory Basis:

Title 10 of the *Code of Federal Regulations* (10 CFR) Part 52, Section 47 and Section 79 require a final safety analysis report (FSAR) to analyze the design and performance of the structures, systems, and components (SSCs). Safety evaluations, performed to support the FSAR, include accident analyses to demonstrate that specified acceptable fuel design limits (SAFDLs) are not exceeded during normal operation, including the effects of anticipated operational occurrences (AOOs).

GDC 10, *Reactor design*, which requires that the reactor core and associated coolant, control, and protection systems be designed with appropriate margin to assure that SAFDLs are not exceeded during any condition of normal operation, including the effects of AOOs.

Issue:

In Supplement 1 to TR-0116-21012-P-A, Revision 1, NuScale provided NSP4 predictions for {{ }}2(a),(c)

Request:

{{ }}2(a),(c) in the same format as "Appendix A to Topical Report Entitled "Applicability Range Extension of NSP4 Critical Heat Flux Correlation: Supplement 1 to TR-0116-21012-P-A, Revision 1," TR-107522-P, Revision 0.

NuScale Response:

NSP4 predictions for the Stern C1 test have been added to Appendix A in the existing format. In addition, the C1 test data is incorporated into the assessment of the Stern database within Section 4 of TR-107522-P.

{{ [

] }}2(a),(c)

NSP4 predictions of the {{

}}2(a),(c)

{{ [

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

Figure 1: Stern and K8500 Tests P/M vs. Local Mass Flux at the minimum CHFR location

{{ [

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

Figure 2: Predicted vs. Measured Local Heat Flux by Test Series

Table 1: NSP4 Statistical Figures-of-Merit for K8500 Test

Parameter {{ [			
KATHY K8500 Uniform			
Mean			
Standard Deviation			
Non-parametric bounds			
Parametric Bound			] }}2(a),(c)

{{

}}2(a),(c)

Table 2: Local Conditions for NSP4 Prediction of K8500 Test

{{ [

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

Table 2: Local Conditions for NSP4 Prediction of K8500 Test

{{ [

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

Definitions:

TEST	Test Identifier
POINT	Test point
Z_{pred}	Elevation of CHF prediction from bottom of heated length, in.
P	Pressure, psia
G_{in}	Approximate inlet mass flux (test matrix value), Mlbm/hr-ft^2
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G	Local mass flux, Mlbm/hr-ft^2
X	Local equilibrium quality
Z_{boil}	Boiling length {{ }}2(a),(c)
{{ }}2(a),(c)	
{{ }}2(a),(c)	
q"(Z_{pred})	Predicted CHF, MBtu/hr-ft^2
F-factor	Modified Tong F-factor
P/M	Predicted-to-measured CHF ratio

Impact on Topical Report:

Topical Report TR-107522, Applicability Range Extension of NSP4 CHF Correlation, has been revised as described in the response above and as shown in the markup provided in this response.

Licensing Topical Report

Applicability Range Extension of NSP4 Critical Heat Flux Correlation

Supplement 1 to TR-0116-21012-P-A, Revision 1, NuScale Power Critical Heat Flux Correlations

~~January 2022~~

Draft Revision 1

Docket: 99902078

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Department of Energy Acknowledgement and Disclaimer

This material is based upon work supported by the Department of Energy under Award Number DE-NE0008928.

Licensing Topical Report

List of Affected Pages

Revision Number	Page Number	Explanation
0	All	Initial Issue
1	All	Revised to address NRC Requests for Additional Information 9899

Table of Contents

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Abstract

The purpose of this topical report supplement is to provide the bases for Nuclear Regulatory Commission approval of an extension to the range of applicability in Tables 7-5 and 8-4 for the NSP4 critical heat flux (CHF) approved in topical report TR-0116-21012-P-A, Revision 1, "NuScale Power Critical Heat Flux Correlations." The correlation and correlation limit justified and approved in the topical report remain unchanged.

Executive Summary

The purpose of this report is to provide the bases for Nuclear Regulatory Commission approval to use the NSP4 CHF correlation in VIPRE-01, within its expanded range of applicability in Table 5-1, along with its associated correlation limit 1.21, for the NuScale safety analysis of the NPM with NuFuel-HTP2™ fuel.

This correlation conforms to acceptance criteria given by the NuScale Design-Specific Review Standard (DSRS) and the requirements of 10 CFR 50, Appendix A, General Design Criterion (GDC) 10.

~~Two independent~~The method~~s~~ of justification {{

}}2(1),(c)~~are provided:~~

~~{{~~

~~}}2(a),(c)~~

1.0 Introduction

1.1 Purpose

The applicable range of the NSP4 CHF correlation contained in TR-0116-21012-P-A, Revision 1 (Reference 6.1.1) was adequate for the NuScale Power Module (NPM) described in the Design Certification Approval (DCA). The range of applicability is expanded to ensure the NSP4 CHF correlation encompasses the operating domain of the NPM at higher rated power levels.

1.2 Scope

This supplement provides justification for extending the applicable range of the mass flux for the NSP4 critical heat flux (CHF) correlation (Reference 6.1.1).This supplement will assess the available CHF data, and justify an extension to the mass flux applicability range for the NSP4 critical heat flux correlation, while retaining the approved correlation limit of 1.21 for safety analysis evaluations of the NPM with NuFuel-HTP2™ fuel.

The numbering of Section 1 through 3 in this document follows that of TR-0116-21012-P-A, Revision 1 in order to assist the reader in relating this supplement to the original topical report. Section 4 provides a description of the methodologiesevaluation and assessment that justifyjustifies the expanded applicability. Section 5 provides a summary of the results, along with the updated applicability range for the NSP4 CHF correlation. Appendix A provides the local thermal-hydraulic parameters for each of the evaluated test series with the NSP4 correlation.

1.3 Abbreviations and Definitions

This section is unchanged relative to the corresponding section of Reference 6.1.1.

2.0 Background

The NuScale topical report TR-0116-21012-P-A, Revision 1, “NuScale Power Critical heat Flux Correlations,” presents the NSP2 and NSP4 critical heat flux (CHF) correlations that have been developed by NuScale to assess CHF performance for normal operation, anticipated operational occurrences (AOOs), and postulated accidents in the NuScale Power Module (NPM) with NuFuel-HTP2™ fuel. In particular, the NRC found the NSP4 CHF correlation acceptable for use in performing safety analyses of the NPM with NuFuel-HTP-2™ fuel, with its associated correlation limit 1.21, over the range of applicability provided in Table 8-4 of TR-0116-21012-P-A, Revision 1.

2.1 Regulatory Requirements

This section is unchanged relative to the corresponding section of Reference 6.1.1.

2.2 NuScale Power Module Fuel Assembly Design

This section is unchanged relative to the corresponding section of Reference 6.1.1.

3.0 Analysis and Experimentation

This section is unchanged relative to the corresponding section of Reference 6.1.1.

4.0 Extension of Mass Flux Range for NSP4 Critical Heat Flux Correlation

4.1 Overview of Mass Flow Range Extension

Two independentThe methods of justification {{

}}2(a),(c) are provided:

{{

}}2(a),(c)

4.1.1 Statistical Assessment

The first method consists of {{

}}2(a),(c)

Data are randomly generated for pressure, axial power shape, power level, inlet mass flux, and inlet temperature. Values for power level, pressure, and inlet mass flux are randomly selected from the uniform distribution on the ranges tabulated in Table 4-1. The inlet temperature data range is a function of the power level, which is used to accommodate the natural circulation design of the NPM, as given by:

{{	
	Equation 4-1
}}2(a),(c)	

{{

}}2(a),(c)

Table 4-1 ~~Data Ranges for Random Parameter Generation~~

	~~Minimum~~	~~Maximum~~
{{		
		}}2(a),(c)

Figure 4-1 ~~Axial Power Shapes~~

~~A simple {{~~

~~}}2(a),(c)~~

Figure 4-2 ~~Closed Channel Nodalization~~

{{

}}2(a),(c)

~~The enthalpy at {{ }}2(a),(c)~~

$H_n = \frac{\sum_{i=1}^{n}[F_{z,i} \cdot \bar{Q}]}{G} + H_0$		Equation 4-2

{{

}}2(a),(c)

{{	
	Equation 4-4
}}2(a),(c)	

{{

}}2(a),(c) Values for CHF are calculated with the NSP4 CHF correlation (Reference 6.1.1; Equation 7-1)

The populations are compared using both the Wilcoxon rank sum test (Reference 6.1.2; Section 25.8) and the squared ranks test (Reference 6.1.2; Section 25.13), which test the median and variance of two samples, respectively.

Wilcoxon rank sum test

Let $\{y_{11}, y_{12}, \ldots, y_{1n}\}$ be a sample of size *n* from a population with median ζ_1 and $\{y_{21}, y_{22}, \ldots, y_{2m}\}$ be an independent sample of size m from a population with median ζ_2. The null hypothesis is H_0: $\zeta_1 = \zeta_2$.

The test statistic for testing H_0 is the sum of ranks from the first sample:

$W = \sum_{i=1}^{n} R(y_{1i})$	Equation 4-5

For the alternative hypothesis, H_1: $\zeta_1 \neq \zeta_2$, H_0 is rejected if $W > w_{1-\alpha/2}(n,m)$ or if $W < w_{\alpha/2}(n,m)$. The critical values of the W statistic are calculated with:

$w_q(m,n) = \frac{n(n+m+1)}{2} + z_q\sqrt{\frac{nm(n+m+1)}{12}}$	Equation 4-6

where z_q is the q[th] quantile of the standard normal distribution.

The test statistic and critical values are tabulated in Table 4-2. Since $w_{\alpha/2} < W < w_{1-\alpha/2}$ the null hypothesis is accepted and the two populations have the same median, and belong to the same distribution.

Table 4-2 Wilcoxon Rank Sum Test for Mass Flux Range Variation

Parameter	Value		
m	{{		
n			
W			
$w_{1-\alpha/2}$			
$w_{\alpha/2}$			}}2(a),(c)

Squared ranks test

From Reference 6.1.2; Section 25.13, let $\{y_{11}, y_{12}, \ldots, y_{1n}\}$ and $\{y_{21}, y_{22}, \ldots, y_{2m}\}$ be independent samples of size *n* and *m* from two populations. The null hypothesis is H_0: $\sigma_1^2 = \sigma_2^2$. Calculate parameters u_i and v_j with:

$$u_i = |y_{1i} - \mu_1|, \; i=1,2,\ldots,n$$
$$v_j = |y_{2j} - \mu_2|, \; j=1,2,\ldots,m \qquad \text{Equation 4-7}$$

where: μ_1 and μ_2 are mean values for population 1 and 2, respectively, and *n* and *m* are the number of observations in population 1 and 2, respectively. Rank the *n+m* observations in the combined samples of u_i's and v_j's. If any values of u_i or v_j are tied, assign to each the average of the ranks that would have been assigned had there been no ties. Denote the ranks by $R(u_i)$ and $R(v_j)$. If there are no ties, the test statistic is:

$$T_1 = \sum_{i=1}^{n} R(u_i)^2 \qquad \text{Equation 4-8}$$

If there are ties, the test statistic is:

$$T_1^* = \frac{T_1 - n\bar{R}^2}{\sqrt{\frac{nm}{(n+m)(n+m-1)}\sum_{k=1}^{n+m} R_k^4 - \left(\frac{nm}{n+m-1}\bar{R}^2\right)^2}} \qquad \text{Equation 4-9}$$

where *n* and *m* are the number of observations in population 1 and 2, respectively,

$$\bar{R}^2 = \frac{1}{n+m}\left[\sum_{i=1}^{n} R(u_i)^2 + \sum_{j=1}^{m} R(v_j)^2\right] \qquad \text{Equation 4-10}$$

and

$$\sum_{k=1}^{n+m} R_k^4 = \sum_{i=1}^{n} R(u_i)^4 + \sum_{j=1}^{m} R(v_j)^4 \qquad \text{Equation 4-11}$$

For the alternative hypothesis, H_1: $\sigma_1^2 \neq \sigma_2^2$, H_0 is rejected if $T_1^* > w_{1-\alpha/2}(n,m)$ or if $W < w_{\alpha/2}(n,m)$. The critical values of the T_1^* statistic are calculated with:

$$w_q(n,m) = \frac{n(n+m+1)(2n+2m+1)}{6} + z_q\sqrt{\frac{nm(n+m+1)(2n+2m+1)(8n+8m+1)}{180}} \qquad \text{Equation 4-12}$$

where z_q is the q[th] quantile of the standard normal distribution.

The test statistic and critical values are tabulated in Table 4-3. Since the null hypothesis is accepted and the two populations have the same variance, and belong to the same distribution.

Table 4-3 Squared Rank Test for Mass Flux Range Variation

Parameter		Value	
H_1	{{		
H_2			
m			
n			
T_1			
$\bar{R}^2$			
$\sum_{k=1}^{n+m} R_k^4$			
T_1^*			
$w_{1-\alpha/2}$			
$w_{\alpha/2}$			}}[2(a),(c)]

Both the median and variance of the two populations are shown to belong to the same distribution. Therefore, extending the NSP4 CHF correlation from 0.635 to 0.700 Mlbm/hr-ft² can be justified based on the premise that using the correlation beyond its original bounds does not alter its predictive capability.

4.2 Stern CHF Data Evaluation

The Stern CHF database covers a much wider range of mass flux as shown in Reference 6.1.1, Table A-1. This data more than adequately covers the extended upper limit of mass flux desired in the NSP4 CHF correlation. The test assemblies for the Stern CHF tests (Reference 6.1.1, Table 3-2) are similar to the NuFuel-HTP2™ design (Reference 6.1.1, Tables 3-6, 3-7, 3-8, and 3-10) as illustrated in Table 4-4. The fuel rod pitch and outer diameter, guide tube diameter, and heated length are all identical between the two. The only difference lies with the spacer grids. Where NuFuel-HTP2™ uses a combination of Framatome HMP™ and HTP™ spacer grids that have built-in mixing features, the grids in Stern testing {{

}}2(a),(c) with NSP4 because the NSP4 CHF correlation is based on the HMP™ and HTP™ spacer grids. However, as pointed out in Reference 6.1.1; Section 3.1.2, "… *at low flows, such as those of the NPM, any mixing benefits provided by the HTP™ design decrease.*" So, the difference in grid spacer type is not expected to significantly affect results {{

}}2(a),(c) In addition, the spacer grid span is {{ }}2(a),(c) for the Stern tests than in the NuFuel-HTP2™ design. This difference is small enough that it will not affect results since there is no variable in the NSP4 CHF correlation accounting for grid span. Therefore, using Stern CHF data to support the justification of increasing the upper mass flux limit of the NSP4 CHF correlation is acceptable.

Table 4-4 Geometry Comparison Between NuFuel-HTP2™ and Stern Test Assemblies

Parameter	NuFuel-HTP2™	Stern	Difference
Fuel rod pitch (in.)	0.496	0.496	0.0%
Fuel rod outer diameter (in.)	0.374	0.374	0.0%
Guide tube outer diameter (in.)	0.482	0.482	0.0%
Heated length (in.)	78.74	78.74	0.0%
Spacer grid type	HMP™/HTP™	{{ }}2(a),(c)	-
Spacer grid span (in.)	{{		}}2(a),(c),ECI

Critical heat flux values are calculated for the Stern test local conditions (Reference 6.1.1, Table A-1) with the NSP4 CHF correlation using VIPRE-01. All VIPRE-01 inputs, including two-phase correlations and mixing coefficients, are used in a manner consistent with the approved NSP4 CHF correlation topical report.

Limiting CHF values (i.e., the CHF at the location of minimum CHFR) are used to form a population. {{

}}2(a),(c) because this is below the lower limit of the NSP4 CHF correlation applicability range. ~~Only t~~The {{

}}2(a),(c)

{{

}}2(a),(c)

The population is divided into twothree sub-populations:

- {{

}}2(a),(c)

, the first including local mass flux values between 0.110 and 0.635 Mlbm/hr·ft², and the second including values greater than 0.635 Mlbm/hr·ft². The predicted-to-measured ratios for these sub-populations are plotted versus mass flux in Figure 4-3. From this figure, it is observed that these three sub-regions occur naturally based on visual trends of P/M versus mass flux. At higher mass fluxes the CHFPredicted-to-measured comparisonpredictions for {{

}}2(a),(c) and generally trending towards more conservative predictions (i.e., lower P/M ratios) than the rest of the data. The general trend in the predicted-to-measured plot in Figure 4-4 {{

}}2(a),(c) [There is significant data scatter when compared to KATHY K9000 and K9100 test predictions with some points over-predicted.] {{

}}2(a),(c) This indicates that the NSP4 CHF correlation under-predicts the measured data and is conservative. {{

}}2(a),(c) The measured-to-predicted trend for mass flux greater than 0.635 Mlbm/hr·ft² is comparable to that for mass flux less than this value, so predictions at higher mass flux are as reliable as those made at lower mass flux. Overall, trends predicted by the NSP4 CHF correlation for Stern data are generally conservative compared with the KATHY test data. The NSP4 CHF correlation conservatively predicts the Stern test data for the entire mass flux range.

Table 4-5 Stern NSP4 Statistical Figure-of-Merits

Parameter	{{			
Mean				
Standard Deviation				
Non-parametric Bound				
Parametric Bound				
Mean				
Standard Deviation				
Non-parametric Bound				
Parametric Bound				
Mean				
Standard Deviation				
Non-parametric Bound				
Parametric Bound				}}2(a),(c)
{{				}}2(a),(c)

Table 4-6 ~~Stern NSP4 Statistical Parameters~~

	~~Data~~	~~Set μ~~	~~Set σ~~	
{{				
				}}2(a),(c)

Figure 4-3 Stern Test P/M Versus Local Mass Flux Values at Minimum CHFR Location

{{

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

Figure 4-4 Stern Test Predicted Versus Measured Local Heat Flux Values

{{

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

5.0 Summary and Conclusions

The upper end of the mass flux range for NSP4 CHF correlation is extended to a value of 0.75 Mlbm/hr·ft². The range extension is validated ~~in two ways: 1) {{ }}2(a),(c) and 2)~~ by using data from a separate CHF test program that contains data ranges greater {{ }}2(a),(c)

~~The first range extension validation is performed in Section 4.1.1. {{ }}2(a),(c) Therefore, it is appropriate that the NSP4 CHF correlation can be extended to an upper range limit of 0.7 Mlbm/hr·ft² with acceptable predictive capabilities.~~

~~The second range extension validation is performed in Section 4.2.~~ Local condition data from~~for~~ {{ }}2(a),(c) are generated using VIPRE-01 with the NSP4 CHF correlation. The measured and predicted values are compared and show that the {{ }}2(a),(c) which demonstrates the NSP4 design limit for the approved domain conservatively bounds the extended domain to 0.75 Mlbm/(hr-ft²). ~~{{ }}2(a),(c) which is conservative.~~

~~The CHF prediction population with mass fluxes greater than 0.635 Mlbm/hr·ft² have comparable mean and standard deviation as that from below 0.635 Mlbm/hr·ft². {{ }}2(a),(c)~~

~~Therefore, the NSP4 CHF correlation predicts Stern data conservatively and demonstrates it is applicable over the mass flux range 0.110 to 0.700 Mlbm/hr·ft².~~

The use of the NSP4 CHF correlation to an upper bound 0.75 Mlbm/(hr-ft²) is validated and appropriate. ~~is validated by both the {{ }}2(a),(c) and with Stern data that is {{ }}2(a),(c)~~ The extended applicability range for the NSP4 CHF correlation is shown in Table 5-1.

Table 5-1 NSP4 CHF Correlation Extended Applicability Ranges

Parameter	Units	Lower Limit	Upper Limit
Pressure	psia	500	2,300
Mass flux	Mlbm/hr·ft²	0.110	0.750~~0.700~~
Local quality	-	n/a	95%
Inlet quality	-	n/a	0%

6.0 References

6.1 Referenced Documents

6.1.1 NuScale Power, LLC, "NuScale Power Critical Heat Flux Correlations," TR-0116-21012-P-A, Revision 1.

6.1.2 U.S. Nuclear Regulatory Commission, "Applying Statistics," NUREG-1475, Revision 1, March 2011.

Appendix A Local Conditions

This appendix provides tabulated parameters for Stern test series U1, ~~and~~ U2, and C1 evaluated with the NSP4 CHF correlation.

Definitions:

TEST	Test identifier
POINT	Test point
Z_{pred}	Elevation of CHF prediction from bottom of heated length, in.
P	Pressure, psia
G_{in}	Approximate inlet mass flux (test matrix value), Mlbm/(hr-ft^2)
ΔT_{sub}	Approximate inlet subcooling (test matrix value), °F
G	Local mass flux, Mlbm/hr-ft^2
X	Local equilibrium quality
Z_{boil}	Boiling length {{ }}2(a),(c)

{{ }}2(a),(c)

{{ }}2(a),(c)

$q''_{pred}(l_{chf})$	Predicted CHF, MBtu/hr-ft^2
F-factor	Modified Tong F-factor
P/M	Predicted-to-measured CHF ratio

Table A-1 ~~Local Conditions for NSP4 Prediction of Stern U1 and U2 Tests~~

{{

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

Table A-1 ~~Local Conditions for NSP4 Prediction of Stern U1 and U2 Tests (Continued)~~

{{

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

Table A-1 ~~Local Conditions for NSP4 Prediction of Stern U1 and U2 Tests (Continued)~~

{{

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

Table A-1 ~~Local Conditions for NSP4 Prediction of Stern U1 and U2 Tests (Continued)~~

{{

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

Table A-1 ~~Local Conditions for NSP4 Prediction of Stern U1 and U2 Tests (Continued)~~

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1 and U2 Tests (Continued)

{{

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

Table A-1 ~~Local Conditions for NSP4 Prediction of Stern U1 and U2 Tests (Continued)~~

{{

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

Table A-1 ~~Local Conditions for NSP4 Prediction of Stern U1 and U2 Tests (Continued)~~

{{

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

Table A-1 ~~Local Conditions for NSP4 Prediction of Stern U1 and U2 Tests (Continued)~~

{{

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

Table A-1 ~~Local Conditions for NSP4 Prediction of Stern U1 and U2 Tests (Continued)~~

{{

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

Table A-1 ~~Local Conditions for NSP4 Prediction of Stern U1 and U2 Tests (Continued)~~

{{

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

Table A-1 ~~**Local Conditions for NSP4 Prediction of Stern U1 and U2 Tests (Continued)**~~

{{

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

Table A-1 ~~Local Conditions for NSP4 Prediction of Stern U1 and U2 Tests (Continued)~~

{{

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

Table A-1 ~~Local Conditions for NSP4 Prediction of Stern U1 and U2 Tests (Continued)~~

~~{{~~

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Table A-1 Local Conditions for NSP4 Prediction of Stern U1, U2, and C1 Tests (Continued)

{{

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

Response to Request for Additional Information
Docket: 99902078

RAI No.: 9899

Date of RAI Issue: 03/21/2022

NRC Question No.: NTR-02

Regulatory Basis:

Title 10 of the *Code of Federal Regulations* (10 CFR) Part 52, Section 47 and Section 79 require a final safety analysis report (FSAR) to analyze the design and performance of the structures, systems, and components (SSCs). Safety evaluations, performed to support the FSAR, include accident analyses to demonstrate that specified acceptable fuel design limits (SAFDLs) are not exceeded during normal operation, including the effects of anticipated operational occurrences (AOOs).

GDC 10, *Reactor design*, which requires that the reactor core and associated coolant, control, and protection systems be designed with appropriate margin to assure that SAFDLs are not exceeded during any condition of normal operation, including the effects of AOOs.

Issue:

In their February 18, 2022, submittal of supplement information, "CHF Topical Supplement, February 3, 2022, Clarification Call Summary", NuScale {{

}}2(a),(c)

Request:

{{

}}2(a),(c)

NuScale Response:

Table 4-5 has been added to TR-107522 in order to provide a quantification of the conservatism and accuracy of the CHF prediction in the higher mass flux range using various figures-of-merit that all demonstrate {{

}}2(a),(c)

{{

}}2(a),(c)

{{

}}2(a),(c)

{{

}}2(a),(c)

Figure 1: Stern (U1/U2/C1) vs. KATHY (K9000/K9100/K9200/K9300) P/M for 'all data' test points binned by mass flux with 95% confidence intervals

{{

}}2(a),(c)

Figure 2: Stern (U1/U2/C1) vs. KATHY (K9000/K9100/K9200/K9300) P/M for 'like-for-like' test points binned by mass flux with 95% confidence intervals

{{

}}2(a),(c)

Figure 3: Stern vs. KATHY P/M absolute difference for 'like-for-like' test points

Table 1: Like-for-like statistical parameters comparing KATHY and Stern

Parameter	KATHY	Stern	Bias
Average	{{		
Standard Deviation			
Non-Parametric Bound			

}}2(a),(c)

{{

}}2(a),(c)

Figure 4: Predicted-to-Measured relative difference as a function of inlet mass flux between NSP4 applied to K8500 and K9100

{{

}}2(a),(c)

Figure 5: P/M relative difference as a function of inlet subcooling between NSP4 applied to K8500 and K9100

Table 2: Like-for-like statistical parameters comparing K8500 (non-mixing) and K9100 (mixing) tests

Parameter	K8500	K9100	Bias
Average	{{		
Standard Deviation			
Maximum Bias			

}}2(a),(c)

{{

}}2(a),(c)

Figure 6: Stern and K8500 Predicted CHF effects from Mass Flux terms in the NSP4 correlation

Impact on Topical Report:

Topical Report TR-107522, Applicability Range Extension of NSP4 CHF Correlation, has been revised as described in the response above and as shown in the markup provided in this response and as shown in the response to RAI Question NTR-01.

September 30, 2022

Docket: 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 Supplemental Response to NRC Request for Additional Information (RAI No. 9899) on the NuScale Topical Report, "Critical Heat Flux," TR-0116-21012, Revision 1-A

REFERENCES:
1. NRC Letter Final Request for Information eRAI 9899 (Proprietary), dated March 14, 2022, RAI# 9899
2. NuScale Power, LLC Response to NRC "Request for Additional Information No. 9899 RAI# 9899," dated July 20, 2022
3. NuScale Topical Report Critical Heat Flux, dated December 2018, TR-0116-21012

The purpose of this letter is to provide NuScale's supplemental response to NRC Requests for Additional Information (RAI), RAI# 9899, noted in the References above. The responses to the individual RAI questions are provided in the attached Enclosures.

This letter contains NuScale's supplemental response to the following RAI Question from NRC RAI# 9899:

- NTR-01S1

Enclosures are grouped with all proprietary version responses first, followed by all nonproprietary version responses. NuScale requests that the proprietary version be withheld from public disclosure in accordance with the requirements of 10 CFR § 2.390. The enclosed affidavit supports this request. The proprietary enclosures have been deemed to contain Export Controlled Information. This information must be protected from disclosure per the requirements of 10 CFR § 810.

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

Please contact Thomas Griffith at 541-452-7813 or at tgriffith@nuscalepower.com if you have any questions.

Sincerely,

Mark W. Shaver

Mark Shaver
Manager, Licensing
NuScale Power, LLC

Distribution: Bruce Bavol, NRC
Getachew Tesfaye, NRC
Michael Dudek, NRC

Enclosure 1: NuScale Supplemental Response to NRC Request for Additional Information RAI# 9899, proprietary

Enclosure 2: NuScale Supplemental Response to NRC Request for Additional Information RAI# 9899, nonproprietary

Enclosure 3: Affidavit of Mark Shaver, AF-126875

Enclosure 2:

NuScale Supplemental Response to NRC Request for Additional Information eRAI No. 9899, nonproprietary

Response to Request for Additional Information
Docket: 99902078

RAI No.: 9899
Date of RAI Issue: 08/26/2022

NRC Question No.: NTR-01S1

Regulatory Basis:

Title 10 of the *Code of Federal Regulations* (10 CFR) Part 52, Section 47 and Section 79 require a final safety analysis report (FSAR) to analyze the design and performance of the structures, systems, and components (SSCs). Safety evaluations, performed to support the FSAR, include accident analyses to demonstrate that specified acceptable fuel design limits (SAFDLs) are not exceeded during normal operation, including the effects of anticipated operational occurrences (AOOs).

GDC 10, *Reactor design*, which requires that the reactor core and associated coolant, control, and protection systems be designed with appropriate margin to assure that SAFDLs are not exceeded during any condition of normal operation, including the effects of AOOs.

Issue:

In Supplement 1 to TR-0116-21012-P-A, Revision 1, NuScale provided NSP4 predictions for {{ }}2(a),(c)

Request:

{{ }}2(a),(c) in the same format as "Appendix A to Topical Report Entitled "Applicability Range Extension of NSP4 Critical Heat Flux Correlation: Supplement 1 to TR-0116-21012-P-A, Revision 1," TR-107522-P, Revision 0.

Clarification Questions:

NRC is seeking the following information to support finalizing the safety evalution:

1. Please provide the NSP4 predictions for the U1 runs {{ }}2(a),(c) in the same format as "Appendix A to Topical Report Entitled "Applicability Range Extension of NSP4 Critical Heat Flux Correlation: Supplement 1 to TR-0116-21012-P-A, Revision 1," TR-107522-P, Revision 0.

2. In Supplement 1 to TR-0116-21012-P-A, Revision 1, NuScale stated that data which had {{ }}2(a),(c) Based on this justification, this data was not provided in the tables given in Appendix A of the Supplement. However, it was later determined that another subset of data was not given in the Appendix for different reasons. For Supplement 1, {{ }}2(a),(c) in which NSP4 predictions were not provided in Appendix A.

NuScale Response:

NuScale is supplementing its response to RAI 9899, Question NTR-01 that was originally transmitted in letter RAIO-118038 dated July 20, 2022. The previously submitted RAI response for NTR-01 remains unchanged. This supplemental response provides additional information to respond to clarification questions that were discussed with the NRC on August 25, 2022.

Since the local mass flux was outside of the range of applicability being requested for approval in Section 4.1, NuScale did not include several data points in the analysis or in Table A-1 presented in TR-107522, Revision 1. At the NRC's request, these screened data points that have {{ }}$^{2(a),(c)}$, and that have mass fluxes greater than 0.750 Mlbm/(hr-ft^2) are presented in Table 1 in the same format as Appendix A of the topical report.

NuScale has additionally reviewed the data analysis for topical report TR-0116-21012-P-A, Revision 1, and has identified that a total of {{ }}[2(a),(c)] test series were excluded from the NSP4 CHF correlation development and from Appendix A, Table A-4. The excluded test points were those that have {{ }}[2(a),(c)], which is consistent with the applicability domain for NSP4. The exclusion of these data from Appendix A is consistent with the NuScale practice of presenting data {{ }}[2(a),(c)] as noted in NRC audit summary dated September 27, 2017 (ML17264B163).

Table 1: Local Conditions for Test Points with Local Mass Flux Above Bin Limit

{{

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

Impact on Topical Report:

There are no impacts to Topical Report TR-107522, Applicability Range Extension of NSP4 CHF Correlation, as a result of this response.

Enclosure 3:

Affidavit of Mark W Shaver, AF-138877

NuScale Power, LLC
1100 NE Circle Blvd., Suite 200 Corvallis, Oregon 97330 Office 541.360-0500 Fax 541.207.3928
www.nuscalepower.com

NuScale Power, LLC

AFFIDAVIT of Mark W. Shaver

I, Mark W. Shaver, state as follows:

(1) I am the Acting Director 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 topical report reveals distinguishing aspects about the method by which NuScale develops its Applicability Range Extension of NSP4 Critical Heat Flux Correlation.

NuScale has performed significant research and evaluation to develop a basis for this method 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 the Enclosure 1 to the "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, 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 4/28/2023.

Mark W. Shaver

Mark W. Shaver

Enclosure 4:

Affidavit of Morris Byram, Framatome

NuScale Power, LLC
1100 NE Circle Blvd., Suite 200 Corvallis, Oregon 97330 Office 541.360-0500 Fax 541.207.3928
www.nuscalepower.com

A F F I D A V I T

1. My name is Morris Byram. I am Product Manager, Licensing & Regulatory Affairs for Framatome Inc. (Framatome) and as such I am authorized to execute this Affidavit.

2. I am familiar with the criteria applied by Framatome to determine whether certain Framatome information is proprietary. I am familiar with the policies established by Framatome to ensure the proper application of these criteria.

3. I am familiar with the Framatome information contained in the Document that is Enclosure 1 to the NuScale Power,LLC letter Number LO-138876 with subject "NuScale Power, LLC Submittal of the Approved Version of Topical Report "Applicability Range Extension of NSP4 Critical Heat Flux Correlation, Supplement 1 to TR-0116-21012-P-A, Revision 1," TR-107522, Revision 1," and referred to herein as "Document." Information contained in this Document has been classified by Framatome as proprietary in accordance with the policies established by Framatome for the control and protection of proprietary and confidential information.

4. This Document contains information of a proprietary and confidential nature and is of the type customarily held in confidence by Framatome and not made available to the public. Based on my experience, I am aware that other companies regard information of the kind contained in this Document as proprietary and confidential.

5. This Document has been made available to the U.S. Nuclear Regulatory Commission in confidence with the request that the information contained in this Document be withheld from public disclosure. The request for withholding of proprietary information is made in accordance with 10 CFR 2.390. The information for which withholding from disclosure is

requested qualifies under 10 CFR 2.390(a)(4) "Trade secrets and commercial or financial information."

6. The following criteria are customarily applied by Framatome to determine whether information should be classified as proprietary:

(a) The information reveals details of Framatome's research and development plans and programs or their results.

(b) Use of the information by a competitor would permit the competitor to significantly reduce its expenditures, in time or resources, to design, produce, or market a similar product or service.

(c) The information includes test data or analytical techniques concerning a process, methodology, or component, the application of which results in a competitive advantage for Framatome.

(d) The information reveals certain distinguishing aspects of a process, methodology, or component, the exclusive use of which provides a competitive advantage for Framatome in product optimization or marketability.

(e) The information is vital to a competitive advantage held by Framatome, would be helpful to competitors to Framatome, and would likely cause substantial harm to the competitive position of Framatome.

The information in this Document is considered proprietary for the reasons set forth in paragraph 6(a), 6(b), and 6(c) above.

7. In accordance with Framatome's policies governing the protection and control of information, proprietary information contained in this Document has been made available, on a limited basis, to others outside Framatome only as required and under suitable agreement providing for nondisclosure and limited use of the information.

8. Framatome policy requires that proprietary information be kept in a secured file or area and distributed on a need-to-know basis.

9. The foregoing statements are true and correct to the best of my knowledge, information, and belief.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on: (4/28/2023)

BYRAM Morris Digitally signed by BYRAM Morris
Date: 2023.04.28 13:08:41 -07'00'

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