December 19, 2019

Docket No. PROJ0769

U.S. Nuclear Regulatory Commission
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Rockville, MD 20852-2738

SUBJECT: NuScale Power, LLC Submittal of "NuScale Applicability of AREVA Method for the Evaluation of Fuel Assembly Structural Response to Externally Applied Forces," TR-0716-50351, Revision1

REFERENCES: Letter from NuScale Power LLC, to Nuclear Regulatory Commission "NuScale Power, LLC Submittal of Topical Report TR-0716-50351, 'NuScale Applicability of AREVA Method for the Evaluation of Fuel Assembly Structural Response to Externally Applied Forces,' Revision 0 (NRC Project 0769)," dated September 30, 2016

NuScale Power, LLC (NuScale) hereby submits Revision 1 of the "NuScale Applicability of AREVA Method for the Evaluation of Fuel Assembly Structural Response to Externally Applied Forces" (TR-0716-50351).

Enclosure 1 contains the proprietary version of the report entitled "NuScale Applicability of AREVA Method for the Evaluation of Fuel Assembly Structural Response to Externally Applied Forces." NuScale requests that the proprietary version be withheld from public disclosure in accordance with the requirements of 10 CFR § 2.390. The enclosed affidavit (Enclosure 3) pertains to Framatome Inc. (formerly AREVA Inc.) proprietary information to be withheld from the public. Framatome proprietary information is denoted by bolded straight brackets (i.e., "**[ ]**"). Enclosure 2 is 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 feel free to contact Matthew Presson at 541-452-7531 or at mpresson@nuscalepower.com if you have any questions.

Sincerely,

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Enclosure 1: “NuScale Applicability of AREVA Method for the Evaluation of Fuel Assembly Structural Response to Externally Applied Forces,” TR-0716-50351-P, Revision 1, proprietary version

Enclosure 2: “NuScale Applicability of AREVA Method for the Evaluation of Fuel Assembly Structural Response to Externally Applied Forces,” TR-0716-50351-NP, Revision 1, nonproprietary version

Enclosure 3: Affidavit of Gayle Elliott, Framatome, Inc.

Enclosure 1:

"NuScale Applicability of AREVA Method for the Evaluation of Fuel Assembly Structural Response to Externally Applied Forces," TR-0716-50351-P, Revision 1, proprietary version

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Enclosure 2:

"NuScale Applicability of AREVA Method for the Evaluation of Fuel Assembly Structural Response to Externally Applied Forces," TR-0716-50351-NP, Revision 1, nonproprietary version

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Licensing Topical Report

NuScale Applicability of AREVA Method for the Evaluation of Fuel Assembly Structural Response to Externally Applied Forces

December 2019

Revision 1

Docket: PROJ0769

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Abstract

This topical report demonstrates the applicability of *PWR Fuel Assembly Structural Response to Externally Applied Dynamic Excitations*, ANP-10337P-A (Reference 7.0-1) to the NuScale fuel assembly designed for use in the NuScale Power Module. The generic methodology described in ANP-10337P-A is used to evaluate the structural response of the NuScale fuel assembly to dynamic loads applied during seismic and loss-of-coolant accident (LOCA) events. Additional justification is provided for areas of the methodology that require special consideration due to unique features of the NuScale fuel assembly.

NuScale Power, LLC (NuScale) is submitting this topical report for Nuclear Regulatory Commission (NRC) approval to apply the methodology described in ANP-10337P-A to the NuScale fuel assembly design and for approval of the NuScale design-specific damping values. A summary of the application results are being submitted for review and approval as part of the NuScale Design Certification Application.

Executive Summary

This report demonstrates the applicability of *PWR Fuel Assembly Structural Response to Externally Applied Dynamic Excitations*, ANP-10337P-A (Reference 7.0-1) to the NuScale fuel assembly designed for use in the NuScale Power Module. The generic methodology described in ANP-10337P-A is used to evaluate the structural response of the NuScale fuel assembly to dynamic loads applied during seismic and loss-of-coolant accident (LOCA) events, consistent with the guidance in Standard Review Plan Section 4.2 Appendix A, *Evaluation of Fuel Assembly Structural Response to Externally Applied Forces*, NUREG-0800.

The report provides an evaluation of each chapter of ANP-10337P-A with regard to NuScale applicability, including additional justification for areas impacted by NuScale-specific design parameters. The application of the methodology for the NuScale fuel design is being provided in the Design Certification Application.

The ANP-10337P-A methodology is applicable to any pressurized water reactor (PWR) fuel assembly geometry that can be characterized by the defined testing and model benchmarking processes and any reactor core geometry for which the seismic and LOCA boundary condtions can be defined. This report systematically demonstrates that the NuScale fuel design can be modeled and analyzed utilizing this methodology.

The report identifies three specific NuScale design differences and provides further justification or adaptation to demonstrate applicability:

1. The NuScale fuel assembly is shorter than typical PWR designs. To address this difference, an evaluation is provided to demonstrate that the modeling and benchmarking process adequately characterizes the NuScale fuel design.
2. The experimental characterization of the frequency response of the NuScale fuel design is limited to the first three natural frequencies. This difference is shown to have no impact on the resulting fuel assembly model.
3. The contribution of axial coolant flow to the NuScale fuel assembly damping is expected to be much less than that for other operating PWRs. To address this difference, NuScale-specific fuel assembly damping values are established.

To meet the requirements of ANP-10337P-A, the report provides an explicit demonstration of the applicability of grid impact modeling elements used in the generic methodology.

Based on the justifications and evaluations provided in this report, the ANP-10337P-A methodology with NuScale design-specific damping values can be applied to structural response analyses of the NuScale fuel design as part of the NuScale Design Certification Application.

1.0 Introduction

1.1 Purpose

This report demonstrates the applicability of *PWR Fuel Assembly Structural Response to Externally Applied Dynamic Excitations*, ANP-10337P-A (Reference 7.0-1), to the NuScale fuel assembly designed for use in the NuScale Power Module. The generic methodology described in ANP-10337P-A is used to evaluate the structural response of the NuScale fuel assembly to dynamic loads applied during seismic and loss-of-coolant accident (LOCA) events, consistent with the guidance in Standard Review Plan Section 4.2 Appendix A, *Evaluation of Fuel Assembly Structural Response to Externally Applied Forces*, NUREG-0800 (Reference 7.0-2).

NuScale Power, LLC is submitting this topical report for Nuclear Regulatory Commission (NRC) approval to apply the methodology described in ANP-10337P-A to the NuScale fuel assembly design.

1.2 Scope

In order to demonstrate the applicability of ANP-10337P-A to the NuScale fuel assembly, this report:

- Provides an evaluation of each chapter of ANP-10337P-A with regard to NuScale applicability.
- Provides additional justification for areas of the methodology that require special consideration due to unique features of the NuScale fuel assembly.
- Summarizes selected elements of the NuScale fuel assembly modeling to enhance the applicability justification.

This report does not provide results of the full suite of characterization tests and the structural response analyses of the NuScale fuel. A summary of the application results are being submitted for review and approval as part of the NuScale Design Certification Application.

1.3 Abbreviations

Table 1-1. Abbreviations

Term	Definition
BOL	Beginning of Life
CFR	Code of Federal Regulations
EOL	End of Life
°F	Degrees Fahrenheit
Ft/s	Feet per Second
GDC	General Design Criteria
ID	Inner Diameter
Kg U	Kilograms of uranium
kW/m	Kilowatts per meter
LOCA	Loss-of-Coolant Accident
MWt	Megawatt thermal
NRC	Nuclear Regulatory Commission
OD	Outer Diameter
Psia	Pounds per Square Inch – Absolute
Psig	Pounds per Square Inch – Gauge
PWR	Pressurized Water Reactor
R^2	Coefficient of determination
RCS	Reactor Coolant System
RFT	reactor flange tool
SER	Safety Evaluation Report
SRP	Standard Review Plan

2.0 Background

ANP-10337P-A defines a generic methodology to evaluate the structural response of pressurized water reactor (PWR) fuel assembly designs subjected to dynamic loads under seismic and LOCA events. This report demonstrates that this method is applicable to the NuScale fuel design.

To assist in the review of the applicability of the methodology, a brief summary of the NuScale fuel design is provided below.

<u>Welded Fuel Assembly Structure</u>

The NuScale 17x17 fuel assembly design is a reduced-height version of AREVA's 17x17 PWR fuel designs for Westinghouse-type reactors. The total, nominal height of the fuel assembly is 94 inches (not including hold-down springs). Due to the reduced height and the use of span lengths between spacer grids that are typical for operating PWR plants, the assembly has a total of five spacer grids. The HTP™ grids are welded to the guide tubes, while the HMP™ grid is captured by rings welded to the guide tubes. The design includes features as described in the following subsections.

<u>Fuel Rod with Alloy M5® Fuel Rod Cladding</u>

The fuel rod design features M5® cladding. The seamless M5® cladding encapsulates ceramic UO_2 pellets that are cylindrically shaped with a spherical dish at each end. The fuel rod has an internal spring system that axially restricts the position of the fuel stack within the rod, preventing the formation of gaps during shipping and handling while allowing for the expansion of the fuel stack during operation. The lower end cap has a bullet-nose shape to provide a smooth flow transition in addition to facilitating insertion of the rods into the spacer grids during assembly. The upper end cap has a grippable shape that allows for the removal of the fuel rods from the fuel assembly if necessary, which is typical of AREVA fuel for operating PWR plants.

The nominal density of the pellets is 96 percent theoretical density with a possible enrichment up to 4.95 weight percent ^{235}U.

<u>Zircaloy-4 HTP™ upper and intermediate spacer grids</u>

The four HTP™ spacer grids that occupy the top four grid positions are formed from interlocking strips that are welded at all intersections and welded to the side plates. Each grid strip includes a pair of strips welded back-to-back to produce flow channels. The design creates a flow path that is slanted at its outlet, thus causing a vortex flow pattern under normal PWR operating conditions. The spacer grid design creates line contacts with the fuel rod, which provide resistance to grid-to-rod fretting relative to traditional point-contact spacer grid designs. The HTP™ grids on the NuScale design are identical to those used on AREVA's 17x17 PWR product.

Alloy 718 HMP™ Lower Spacer Grid

The HMP™ spacer grid resembles the HTP™ spacer grid with respect to spring design, rod-to-grid surface contact, and manufacturing. The HMP™ spacer grid, however, has enhanced strength and relaxation characteristics, and straight (non-mixing) flow channels. The HMP™ grid on the NuScale design is identical to those used on AREVA's 17x17 PWR product.

Bottom Nozzle with Mesh Filter Plate

The 304 stainless steel bottom nozzle consists of a cast frame of ribs connecting the guide tube locations. A high strength A-286 alloy mesh filter plate is pinned to the top of the frame and held in place by shoulder screws at each of the 24 guide tube locations.

Zircaloy-4 MONOBLOC™ Guide Tubes

The MONOBLOC™ guide tubes have a constant outer diameter and a reduced inner diameter that forms the guide tube dashpot. The added thickness in the dashpot of the MONOBLOC™ guide tube increases the lateral stiffness of the fuel assembly. The MONOBLOC™ feature is common to the AREVA 17x17 PWR fuel designs.

Reconstitutable Top Nozzle

The top nozzle consists of a 304-stainless steel frame that is attached to the fuel assembly with quick disconnect features at each of the 24 guide tube locations. The NuScale top nozzle design has different requirements with respect to the through-hole in the grillage to accommodate the NuScale top-entry incore detectors. The top nozzle design incorporates four sets of two-leaf hold-down springs made of Alloy 718.

Table 2-1 provides additional information on the NuScale fuel design and identifies the differences between the NuScale and AREVA 17x17 PWR fuel design. The only difference pertinent to the fuel assembly structural response is the fuel assembly height.

Table 2-1. NuScale fuel design parameters

Parameter	NuScale Fuel Design	AREVA 17x17 PWR
Fuel rod array	17 x 17	17 x 17
Fuel rod pitch (inch)	0.496	0.496
Fuel assembly pitch (inch)	8.466	8.466
Fuel assembly height (inch)*	94.0	159.45
Number of guide tubes per bundle	24	24
Dashpot region inner diameter (inch)	0.397	0.397
Dashpot region outer diameter (inch)	0.482	0.482
Inner diameter above transition (inch)	0.450	0.450
Outer diameter above transition (inch)	0.482	0.482
Number of instrument tubes per bundle	1	1
ID (inch)	0.450	0.450
OD (inch)	0.482	0.482
Number of fuel rods per bundle	264	264
Cladding outer diameter (inch)	0.374	0.374 and 0.376
Cladding inner diameter (inch)	0.326	0.326
Length of total active fuel stack (inch)*	78.74	144
Fuel pellet OD (inch)	0.3195	0.3195
Fuel pellet density (% theoretical density)	96	96
Spacer grid span lengths (inch)	20.1	20.6
Fuel rod internal pressure (psig)	215	315

* Height is measured from the seating surface of the bottom nozzle to the top of the post on the top nozzle. Dimension does not include hold-down springs.

Table 2-2 provides the operating conditions representative of the NuScale design.

Table 2-2. NuScale operating conditions

Parameter	NuScale Design Value	AREVA 17x17 PWR Value
Rated thermal power (MWt)	160	3455
Average coolant velocity (ft/s)	3.1	16
System pressure (psia)	1850	2280
Core tave (°F)	547	584
Linear heat rate (kW/m)	8.2	18.0
RCS inlet temperature (°F)	503	547
RCS Reynolds Number	76,000	468,000
Fuel assemblies in core	37	193
Fuel assembly loading (kgU)	249	455
Core loading (kgU)	9,213	87,815

In addition to the operating condition given in Table 2-2, the NuScale design also includes the condition where the reactor core is placed on the reactor flange tool (RFT) during refueling activities. When the core is in this configuration, the fuel assemblies remain in the core cavity with the same lower and upper core plate engagement as during operation. The core is submerged in water at a temperature range of 65 degrees F to 110 degrees F and the control rods are completely inserted.

2.1 Regulatory Requirements

Section 3.0 of ANP-10337P-A identifies the regulatory requirements and guidance addressed by the generic methodology. Specifically, the methodology addresses the following requirements as they relate to the structural requirements of a fuel assembly subjected to externally applied loads from earthquakes and postulated pipe breaks:

- GDC 2 – Design bases for protection against natural phenomena
- GDC 27 – Combined reactivity control systems capability
- GDC 35 – Emergency core cooling
- 10 CFR Part 50 Appendix S – Earthquake engineering criteria for nuclear power plants
- 10 CFR 50.46 – Acceptance criteria for emergency core cooling systems for light-water nuclear power reactors

The methodology addresses these regulatory requirements consistent with guidance in SRP Section 4.2 (Reference 7.0-2).

This topical report demonstrates that the regulatory requirements and demonstration methods defined in ANP-10337P-A are applicable to the NuScale fuel design.

3.0 Review of ANP-10337P-A Topical Report

PWR Fuel Assembly Structural Response to Externally Applied Dynamic Excitations, ANP-10337P-A defines the methodology for performing the evaluation of the fuel assembly structural response to externally applied forces (i.e., seismic and LOCA excitations) for PWRs. The methodology corresponds to the NRC guidance provided in Chapter 4.2, Appendix A of the Standard Review Plan (NUREG-0800). This section addresses the applicability of ANP-10337P-A to the NuScale fuel assembly.

3.1 Applications

ANP-10337P-A defines the AREVA methodology that can be applied generically to evaluate the structural response of fuel assemblies to externally applied forces. This evaluation methodology starts with the execution of design characterization testing in order to define fundamental, design-specific fuel assembly response characteristics such as natural frequencies, stiffness, damping, etc. These characteristics are applied to a generic structural model architecture in order to build design-specific models capable of simulating the fuel assembly structural response. Thus, the methodology is independent of the design being analyzed and can be used to represent the structural response of any PWR fuel assembly. Plant-specific applications are achieved through the geometry of the model boundary conditions (core dimensions, etc.) and inputs (e.g. core plate motion time histories).

An evaluation of the content of each chapter of ANP-10337P-A and its applicability to the NuScale fuel assembly is provided below. Items for which applicability to the NuScale design requires additional justification have been highlighted and are addressed in Section 3.3.

Chapter 1 Introduction

This chapter identifies the purpose and provides an overview of ANP-10337P-A. As stated in this chapter, the method is generically applicable to PWR fuel assembly designs.

Chapter 1 of ANP-10337P-A is applicable to the NuScale fuel assembly in its entirety.

Chapter 2 Applicability

This chapter establishes the generic applicability of the methods to PWR fuel assembly designs. As noted, “PWR fuel designs exhibit a similar geometry and structure that is appropriately represented by the modeling architecture defined in this topical report.” The chapter provides a generic physical description of PWR fuel assemblies and components that is consistent with the design of the NuScale fuel assembly as summarized in Section 2.0 of this report.

To provide further justification, the following key statements from ANP-10337P-A Chapter 2.0 are evaluated with respect to the applicability of this method to NuScale fuel.

1. "… this methodology is applicable to any fuel assembly geometry that can be characterized by the testing and model benchmarking processes defined in this topical."

   The NuScale fuel design is subjected to the entire testing program defined in Table 6-4 of ANP-10337P-A. Similarly, the model benchmarking activity follows the process defined in ANP-10337P-A. These testing and benchmarking activities are suitable and sufficient to characterize the structural response of the NuScale fuel assembly as demonstrated below. Thus, the conditions of the statement from the methodology topical report are satisfied and the methodology can be used to simulate NuScale fuel. A more detailed demonstration of an application of this testing and modeling to NuScale fuel is provided in Section 3.3.4.

2. "… this methodology can be applied to any reactor core geometry for which the seismic and LOCA boundary conditions can be defined."

   The reactor geometry for NuScale (i.e., upper and lower core plates and heavy reflector) is consistent with a typical PWR with regard to the boundary conditions addressed in Section 5.2.2.1 of ANP-10337P-A. The seismic and LOCA boundary conditions will be defined in the application of the method.

3. "Section 2.1 provides a discussion of typical PWR fuel assembly structure, but the specific fuel designs discussed are for illustration only and do not limit the range of applicability of this methodology."

   The NuScale fuel assembly structure is consistent with the description of the structure provided in Chapter 2 of ANP-10337P-A. The fuel assembly is constructed in the same manner and using the same components described in this chapter. Furthermore, the cross-sectional geometry is the same as one of the representative designs presented in Chapter 2. As such, the modeling and analytical approaches defined throughout ANP-10337P-A are directly relevant and applicable to the NuScale fuel, with only a few exceptions addressed in this report. In terms of specific fuel design differences, the NuScale fuel design is outside of the range of PWR designs presented in Table 2-1 of ANP-10337P-A only in terms of overall length and number of spacer grids. The modeling approach defined in ANP-10337P-A can still be applied to represent the NuScale geometry because of the consistency in components and cross-sectional geometry. The effect of a shorter bundle and fewer spacer grids is addressed in Section 3.3 of this report. The effect of these design differences will be measured and characterized as an outcome of the required design testing.

4. "Section 2.2 does identify specific spacer grid behavior that must be satisfied for the methodology defined herein to be applicable to a given PWR fuel design."

   In Section 2.2, ANP-10337P-A defines one generic restriction to the use of the method in that [

   ] is demonstrated in more

detail in Section 3.3.4 and Appendix A. Since the HTP™ grid used in the NuScale design is identical to the grid cited in the sample problem for ANP-10337P-A, this potential limitation on the applicability of the methodology is satisfied.

In summary, the NuScale design is consistent with the general conditions defined in Chapter 2 of ANP-10337P-A. Therefore, the range of applicability defined in this chapter encompasses the NuScale design. The differences in assembly length and number of spacer grids are addressed in Section 3.3 of this report. Compliance to the requirement defined in Section 2.2 of ANP-10337P-A is demonstrated in Section 3.3.4 and Appendix A.

Chapter 3 Regulatory Requirements

Chapter 3 reviews the regulatory requirements that are relevant to this methodology. These requirements include Appendix A (GDC 2, 27, and 35) and Appendix S of 10 CFR Part 50 and 10 CFR 50.46. In addition, this chapter reviews the NRC guidance from the Standard Review Plan Section 4.2 that pertains to these requirements (primarily Appendix A).

The requirements of Appendices A (GDC 2, 27, and 35), and S of 10 CFR Part 50, 10 CFR 50.46 are directly applicable to the NuScale design. The guidance of SRP Section 4.2 Appendix A is directly applicable and is implemented in ANP-10337P-A.

The same regulatory requirements identified in ANP-10337P-A Chapter 3 are applicable to the NuScale Power Module; therefore, this chapter is applicable to the NuScale design.

When the reactor is placed in the RFT during refueling operations, some of the regulatory requirements are already inherently met. In this case, the LOCA event is not considered and control rod insertion and coolable geometry are already satisfied since the reactor is at ambient temperature conditions. The requirement that fuel rod mechanical fracture will not occur due to seismic loads remains applicable.

Chapter 4 Acceptance Criteria

Chapter 4 establishes the appropriate selection of acceptance criteria in order to satisfy the regulatory requirements specified in Chapter 3. In general, this chapter establishes criteria to evaluate spacer grid impact loads and allowable stresses for non-grid components.

Like the regulatory requirements in Chapter 3, these criteria are generic to PWR fuel. The NuScale fuel design uses the same components and structure as the PWR designs presented in Chapter 2 of ANP-10337P-A; therefore, the criteria defined in this chapter can be applied to the NuScale design to demonstrate compliance to the regulatory requirements with the following minor clarification:

- Section 4.2.2 of ANP-10337P-A justifies excluding the evaluation of hold-down springs for accident condition loads based on specific designs of fuel assemblies and

reactor core internals. The justification for Westinghouse designs applies to the NuScale design because both fuel types use the same design of top nozzle and hold-down spring system.

Chapter 5 Model Architecture

Chapter 5 provides a description of the generic modeling approach that is used to represent any fuel design in seismic and LOCA analyses. Independent horizontal and vertical models are defined to simulate the fuel assembly response in those directions. The chapter presents in detail the models and identifies the required model inputs for both horizontal and vertical response analyses.

As noted in the evaluation of Chapter 2, this modeling approach is generally applicable to the NuScale design due to the fact that the NuScale fuel is constructed with the same components and with the same cross-sectional geometry as designs considered in ANP-10337P-A. Inspection of Table 5-1, Table 5-2, and Figures 5-1 through 5-7 reveals that the models, boundary conditions, and required model inputs apply equally well to NuScale fuel. With the exception of the specific geometry differences noted in the Chapter 2 evaluation (i.e., overall length and number of spacer grids), only one additional distinction can be made from this chapter in applying the methodology to the NuScale design. ANP-10337P-A Section 5.2.1.1 presents three mechanisms that contribute to fuel assembly damping in the horizontal model. In the NuScale design, because of the low flow rate (Table 2-2), the contribution of axial coolant flow to the fuel assembly damping is expected to be much less than for other operating PWRs. As a result, the damping definition provided in ANP-10337P-A is not applicable to NuScale. This difference is addressed in Section 3.3.

The reactor geometry for the NuScale design (e.g. upper and lower core plates and heavy reflector) is consistent with the boundary conditions addressed in Section 5.2.2.1 of ANP-10337P-A.

With the exception noted above, Chapter 5 of ANP-10337P-A is applicable to the NuScale design.

Chapter 6 Model Parameter and Allowable Limits Definition

Chapter 6 establishes the means of defining the criteria introduced in Chapter 4 and the modeling parameters introduced in Chapter 5 using design-specific values. These parameters relate to geometric or material properties that can be established directly from design definition documents, or that require characterization testing to define. The NuScale fuel assembly utilizes identical components, with the same cross-sectional geometry, as designs considered in ANP-10337P-A; therefore, the modeling parameters associated with geometric and material properties are unchanged for the NuScale application. The remaining parameters require characterization testing in order to be defined. The full design characterization testing program identified in Table 6-4 of Chapter 6 in ANP-10337P-A will be applied to the NuScale fuel design. Differences in fuel assembly behavior due to the shorter length or fewer number of spacer grids, as

noted in Chapter 2, will be characterized and accommodated as a result of the testing defined in Chapter 6.

For the seismic analysis when the reactor core is placed in the RFT, Chapter 6 of ANP-10337P-A is applicable, but no conversion of the model parameters to operating temperature is needed since the temperature in the RFT condition is taken as 70 degrees F, which is in the specified range of temperatures. The lateral and vertical models, which are benchmarked at ambient temperature, are used directly. Model parameters that are defined or measured at operating temperature, such as the BOL spacer grid through grid properties, are converted to ambient conditions.

One item from Chapter 6 is potentially affected by the application to NuScale fuel.

- Section 6.1.3 presents damping values to be used in the horizontal model. As noted in the review of Chapter 5, the contribution of axial coolant flow to the fuel assembly damping is expected to be much less than for other operating PWRs. As a result, the damping definition provided in Section 6.1.3 of ANP-10337P-A is not applicable to NuScale. This difference is addressed in Section 3.3.3.

Chapter 6 of ANP-10337P-A is applicable to the NuScale fuel design with the exception of the definition of damping values presented in Section 6.1.3. This item is addressed in Section 3.3.

Chapter 7 Seismic and LOCA Analysis

Chapter 7 defines the process of applying appropriate forcing functions representing seismic or LOCA events to the models described in Chapter 5. Chapter 7 also defines the method of accounting for the combined effect of seismic and LOCA loads. In the horizontal analysis, the model calculates the time-varying displacements and impact forces for assemblies across the core. The results of this analysis are also used for calculating the resulting loads and stresses in the assembly. Similarly, the vertical model calculates a time-varying response from the fuel assembly that is used to evaluate the loading on fuel assembly components.

It was demonstrated above that the development of design-specific models and boundary conditions in accordance with ANP-10337P-A is applicable to the NuScale design. The process to apply these models to determine the fuel assembly structural response to seismic and LOCA events is design independent. Therefore, this chapter is applicable to the NuScale fuel design.

Chapter 8 Non-Grid Component Strength Evaluation Methodology

Chapter 8 defines the process of performing the structural component stress analysis using the loads and deflections generated by the seismic and LOCA analyses described in Chapter 7. Like the modeling approach addressed in Chapters 5 and 6, the analysis approach in Chapter 8 is applicable to NuScale fuel because the fuel design uses the same components and structure, and has the same cross-sectional geometry as designs addressed in ANP-10337P-A.

The process defined in this chapter is generic and remains applicable to the NuScale fuel design.

Chapter 9 References

Chapter 9 lists the references cited throughout ANP-10337P-A and is not evaluated separately.

Appendix A: CASAC Code Description

Appendix A provides a description of the structural code, CASAC, used to carry out the modeling and analysis defined in Chapters 5, 6, and 7 of ANP-10337P-A. The application of CASAC in the analysis of NuScale fuel is appropriate given that the NuScale fuel design uses the same components and structure as the PWR fuel assemblies described in ANP-10337P-A. Therefore, Appendix A is applicable to the NuScale design.

Appendix B: Sample Problem Summary

Appendix B provides the results of the sample problem that accompanies ANP-10337P-A. The sample problem is executed for a 17x17 HTP™ fuel design for Westinghouse reactors. This fuel design has the same cross-sectional geometry as the NuScale fuel design. This section provides insight on the application of the method to a specific fuel design and reactor, but is not directly relevant to the NuScale design.

Appendix C: Test Results Supporting the Fuel Assembly Damping Formulation

Appendix C defines generic fuel assembly damping values that credit operational flow rates for PWRs. However, the reduced flow rate and the shorter fuel assembly length of the NuScale design will necessitate the establishment of a specific damping value for the NuScale fuel design, as addressed in Section 3.3.

Appendix C is not applicable to the NuScale design.

Appendix D: Simulation of the Effects of Irradiation on Dynamic Crush Characteristics with Zirconium Alloy Spacer Grids

Appendix D addresses the treatment of the effects of irradiation in the testing and analysis of zirconium-alloy spacer grids. The effects of irradiation on zirconium-alloy materials are generic, regardless of the fuel or reactor design. Therefore, the conclusions regarding the effect of irradiation on grid behavior, and furthermore, the conclusions regarding how to simulate these effects in testing, are applicable to NuScale fuel. The NuScale fuel design utilizes the 17x17 HTP™ spacer grid that is currently in use in operating plants and for which the effects of irradiation are addressed using the same methods defined in Appendix D.

This appendix is applicable to the NuScale fuel design.

Appendix E: Justification for the Use of Level C Stress Limits to Ensure Guide Tube Functionality

Appendix E provides the basis for the acceptability of using Level C stress limits to ensure guide tube functionality (i.e., control rod insertability) following a seismic or LOCA event. The discussion and data presented in Appendix E are generic to any guide tube geometry. The characterization of guide tube stress states and the definition of the Level C service limit in relation to guide tube geometry are generic. Furthermore, the testing discussed in Appendix E is performed on guide tubes of the same cross-sectional geometry as the NuScale design.

This appendix is applicable to the NuScale fuel design.

3.2 Topical Report Restrictions

This section addresses the Limitations and Conditions (L&Cs) of ANP-10337P-A in the context of the application of this methodology to the NuScale Fuel Assembly design.

L&C #1 Discussion:

L&C #1 imposes requirements on the tested behavior of grids in order to be compliant with the ANP-10337P-A methodology:

1. *Dynamic grid crush tests, must be conducted in accordance with Section 6.1.2.1 of ANP-10337P (as amended by RAI 16), and spacer grid behavior must satisfy the requirements in the TR, the key elements of which are:*
   a. **[ ]**
   b. **[ ]**
   c. **[ ]**

The acceptability of the NuScale grids under L&C #1 has been addressed in *ANP-3712P-000, Framatome Responses to NRC RAI No. 9555 regarding NuScale Topical Report TR-0816-51127* (Reference 7.0-3).

L&C #2 Discussion:

L&C #2 imposes requirements on the maximum allowable deformation of spacer grids:

2. *For fuel assembly designs where spacer grid applied loads are limited based on allowable grid permanent deformation (as opposed to buckling), the following limits from Table 4-1 of the TR apply:*

- a. *For all OBE analyses, allowable spacer grid deformation is limited to design tolerances and* **[** **]**.
- b. *For SSE, LOCA, and combined SSE+LOCA analyses,* **[**

]

The acceptability of the NuScale grids under L&C #2 has been addressed in Reference 7.0-3.

L&C #3 Discussion:

L&C #3 imposes controls and quality requirements on the computer programs implementing the methodology of ANP-10337P-A:

3. *The modification or use of the codes CASAC and ANSYS (or other similar industry standard codes) are subject to the following limitations:*
   - a. *CASAC computer code revisions, necessitated by errors discovered in the source code, needed to return the algorithms to those described in ANP-10337P (as updated by RAIs) are acceptable.*
   - b. *Changes to CASAC numerical methods to improve code convergence or speed of convergence, transfer of the code to a different computing platform to facilitate utilization, addition of features that support effective code input/output, and changes to details below the level described in ANP-10337P would not be considered to constitute a departure from a method of evaluation in the safety analysis. Such changes may be used in licensing calculations without NRC staff review and approval. However, all code changes must be documented in an auditable manner to meet the quality assurance requirements of 10 CFR Part 50, Appendix B.*
   - c. *ANSYS or other industry standard codes may be used if they are documented in an auditable manner to meet the quality assurance requirements of 10 CFR Part 50, Appendix B, including the appropriate verification and validation for the intended application of the code.*

The NuScale analyses use the same code versions employed in the analytical method demonstration in Appendix B of ANP-10337P-A. Therefore, L&C #3 is not a concern.

L&C #4 Discussion:

L&C #4 limits the un-restricted use of the ANP-10337P-A methodology to fuel designs and applications consistent with the operating fleet. Markedly new designs have to be assessed:

4. *This methodology is limited to applications that are similar to the current operating fleet of PWR reactor and fuel designs. The core geometry should be*

comparable to the current fleet, in terms of dimensions, dimension tolerances, fuel assembly row lengths, and the gaps between fuel assemblies. Fuel designs should be comparable to the current fleet, in terms of materials, geometry, and dynamic behavior.

L&C #4 has been addressed in Reference 7.0-3. While in absolute terms the NuScale fuel assembly is different from the operating fleet, this design has been demonstrated to be similar, on a scale basis to the generic fuel assembly of ANP-10337P-A. The available lateral deflections in core when scaled by fuel assembly lengths are smaller for NuScale than those for the generic assembly in ANP-10337P-A. This justifies the extension, on a scale basis, of all considerations and acceptability measures from the generic fuel assembly of ANP-10337P-A to the NuScale assembly. This observation substantiates the conclusion that the NuScale assembly is similar to the generic assembly in the approved methodology of ANP-10337P-A, and the time-phasing method is appropriate in this case.

L&C #5 Discussion:

L&C #5 limits the applicability of the lateral damping formulation to existing designs, and requires an applicability justification or a new formulation for new designs:

5. *ANP-10337P established generic fixed damping values intended to be used for all PWR designs. All applications of this methodology to new fuel assembly designs must consider the continued applicability of the fixed damping values of this methodology. If new materials, new geometry, or new design features of a new fuel assembly design may affect damping, additional testing and/or evaluation to determine appropriate damping values may be required.*

The NuScale fuel assembly is much shorter than the current fleet designs, and the lateral fuel assembly damping has been re-formulated to account for specific test results on short assemblies, the particulars of the axial flow, and the phenomena governing the dynamics of these designs. This formulation is addressed within this document in Appendix 2 and also in *ANP-3591P, Revision 0, AREVA Responses to NRC RAI 8736 (Questions 29611, 29613-29616) regarding TR-0716-50351, "NuScale Applicability of AREVA Method for the Evaluation of Fuel Assembly Structural Response to Externally Applied Forces"* (Reference 7.0-4) (Question 29611).

L&C #6 Discussion:

L&C #6 requests that the fuel rod assessment under faulted conditions be demonstrated.

6. *The ANP-10337P methodology includes the generation of fuel rod loads, but does not provide a means to demonstrate compliance for fuel rod performance under externally applied loads (to applicable acceptance criteria). Applications of this methodology must provide an acceptable demonstration of fuel rod performance.*

The fuel rod analysis is part of the component stress evaluation that was performed for the NuScale fuel design.

L&C #7 Discussion:

L&C #7 requires that when bounding stress analysis of the non-grid components is used, without regard to specific core location, the more stringent limits for control rod locations must be used:

7. *As indicated in ANP-10337P when orthogonal deflections from separate core locations are artificially superimposed to calculate component stresses, the component stresses must be compared against the design criteria associated with control rod positions.*

The margin calculations for the NuScale fuel assembly guide tubes were performed using ASME Service Level C stress limits, which are applicable to control rod locations, therefore L&C #7 is fulfilled.

L&C #8 Discussion:

L&C #8 requires that, in the case when **[** **]**:

8. *In accordance with RG 1.92, the combination of loads for non-grid component evaluation should ideally be based on three orthogonal components (two horizontal and one vertical).* **[** **]**.

The NuScale component stress analysis was performed using a 3-D load combination as discussed in Reference 7.0-3. Therefore, L&C #8 is not a concern.

L&C #9 Discussion:

L&C #9 places a restriction over the range of applicability of **[** **]**:

9. **[** **]**.

This point has been addressed in Reference 7.0-3. The NuScale grid design is the same as the grid in the generic fuel assembly used in the Sample Problem (Appendix B) of ANP-10337P-A. The limitation of L&C #9 has been met.

3.3 NuScale Design Differences and Requirements

To extend the applicability of ANP-10337P-A to include NuScale fuel, the following design differences are addressed:

- NuScale fuel assembly is shorter than typical PWR designs presented in Table 2-1 of ANP-10337P-A.

- The contribution of axial coolant flow to the NuScale fuel assembly damping is expected to be much less than that for other operating PWRs, and thus, the damping values presented in Section 6.1.3 of ANP-10337P-A are not applicable to NuScale fuel.
- In addition to the evaluation of the fuel during operation in the reactor, the NuScale analysis includes a seismic evaluation in which the core is residing in the RFT during refueling operations.

3.3.1 Fuel Assembly Length and Number of Spacer Grids

Although not stated as defining a range of applicability, Table 2-1 of ANP-10337P-A illustrates typical PWR designs to which ANP-10337P-A can be expected to be applied. The NuScale fuel assembly is outside the range of parameters in Table 2-1 in terms of fuel assembly length (shorter) and number of grids (fewer).

- The shorter assembly length of the NuScale fuel design will result in unique dynamic properties of the fuel assembly (i.e., higher stiffness and higher natural frequencies). However, this difference in design is captured in the method defined in ANP-10337P-A because the method requires that fuel assembly models be built to match design-specific experimental dynamic characterization of the fuel design. The expected differences in the dynamic properties of the NuScale fuel assembly due to its shorter length are directly characterized through full-scale prototype testing and the models built to match this tested behavior had negligible error. The application of this method to NuScale with its shorter length is discussed in more detail in Section 3.3.4 and Appendix A.
- The designs in Table 2-1 of ANP-10337P-A have between five and nine intermediate spacer grids, whereas the NuScale fuel design has three intermediate spacer grids. The NuScale fuel assembly has a total of five spacer grids, but following the modeling architecture defined in Section 5.2.1 of ANP-10337P-A, the uppermost and lowermost end grids are not modeled explicitly [ ] As a result, the NuScale fuel assembly model will be represented as a single beam with three rotational nodes at the intermediate grid locations. With three non-fixed degrees of freedom, the model is only capable of accurately representing the fuel assembly response up to the third mode, consistent with the limitations of the experimental testing of the NuScale fuel assembly, in which it is only practical to characterize assembly frequencies up to the third mode (see Section 3.3.2 below). [ ] The application of this fuel assembly model, with three rotational nodes, is demonstrated in Section 3.3.4 and Appendix A of this report and shows negligible error to tested results. Additional studies have demonstrated that results from this modeling approach reflect an appropriate level of mass participation in the dynamic response.

Therefore, with regard to the shorter fuel assembly length and fewer spacer grids, ANP-10337P-A remains applicable to NuScale fuel without modifications.

3.3.2 Deleted

This section is no longer needed.

3.3.3 Fuel Assembly Damping

Section 6.1.3 of ANP-10337P-A defines fuel assembly damping values that are generically applicable to standard PWR fuel designs. However, relative to a standard PWR, the NuScale design will operate with a shorter fuel assembly and reduced flow rates. For these reasons, the damping values defined in Section 6.1.3 of ANP-10337P-A are not applicable to the NuScale design.

Section 5.0 and Appendix B provide details regarding the establishment of NuScale-specific fuel assembly damping values. For the NuScale design, the maximum fuel assembly damping ratio values to be used for the analysis of seismic and LOCA events in place of those defined in Section 6.1.3 of ANP-10337P-A are defined in Table 3-1. These damping values do not credit the additional contribution of damping in flowing water.

Table 3-1. NuScale Fuel Assembly Damping Ratio Values

3.3.4 Reactor Flange Tool Seismic Analysis

3.3.4.1 Model Adjustments

As mentioned in Section 3.1 above, when the reactor core is installed in the RFT, the fuel assembly seismic analysis is performed at ambient temperature. No LOCA analysis is performed because the LOCA accident does not exist in the RFT condition.

The horizontal seismic analysis of the RFT follows the same general procedure as defined in ANP-10337P-A. The single fuel assembly model is benchmarked at room temperature based on the free vibration and forced vibration experimental data (Section 6.1.1 of ANP-10337P-A). The equivalent stiffness (K_{EQ}) and equivalent damping (C_{EQ}) for the spacer grid impact spring are benchmarked at room temperature (Section 6.1.2.2 of ANP-10337P-A). The benchmarked assembly model and impact spring properties are thus unchanged for the RFT seismic analysis. These benchmarked models are applied directly in the analysis without further scaling for higher temperatures, as defined throughout Section 6 of ANP-10337P-A.

Relative to Section 6.1.2.1.1 of ANP-10337P-A, [

]

The fuel assembly damping ratios used in the RFT analysis are consistent with the process defined in Section 5.0 and Appendix B. The in-water damping ratios derived from experiment at [

] The structural damping ratios were measured at 70 degrees F, so no adjustment for temperature is necessary. Flowing water is not credited when the fuel is in RFT conditions and therefore, like the damping values presented in Section 3.3.3, the RFT damping values presented in Table 3-2 only include structural and quiescent water components.

Table 3-2. NuScale Fuel Assembly Damping Ratio Values for RFT Analysis at 70°F

[ ]

The vertical seismic analysis for RFT also follows the same general procedure as defined in ANP-10337P-A. The vertical model is benchmarked at room temperature to axial drop experimental data, and the model parameters are unchanged for the RFT analysis. Therefore, the temperature scaling operations defined in Section 6.2 of ANP-10337P-A are not required for the RFT analysis.

3.3.4.2 Regulatory Requirements

The regulatory requirements defined in Section 3 of ANP-10337P-A are primarily concerned with shutting down the reactor safely and maintaining a safe-shutdown condition. When placed in the RFT, the reactor is already near ambient temperature with control rods inserted; thus, the coolability and control rod insertion requirements are met. Therefore, no design margin calculations are made for the spacer grid impact force, guide tube buckling, or guide tube stress.

The remaining regulatory requirement addresses mechanical fracture of the fuel rod by external forces. The fuel rod loads from the horizontal and vertical seismic events are calculated per Section 8 of ANP-10337P-A for inclusion in the fuel rod faulted stress evaluation.

4.0 NuScale Fuel Characterization

Two areas of fuel characterization are reviewed to provide an explicit demonstration of the application of ANP-10337P-A to NuScale fuel. These two items are reviewed in detail in Appendix A, but a summary is provided in this section.

- Section 2.2 of ANP-10337P-A requires an explicit demonstration of the applicability of grid impact modeling elements.
- Section 3.3 of this document notes that the NuScale fuel assembly is outside the range of typical PWR designs to which ANP-10337P-A is applied in terms of both overall fuel assembly length and the number of spacer grids. The application of the single fuel assembly model described in Section 5.2.1 of ANP-10337P-A to the NuScale design, with a shorter overall length and fewer spacer grids, is demonstrated.

4.1 Spacer Grid Behavior

Under lateral impacts over the range of application, Section 2.2 of ANP-10337P-A specifies that [

]

The NuScale fuel design utilizes the same 17x17 HTP™ spacer grid that is currently in use in operating plants. Thus, this behavior is well established for this existing grid design. Figure A.2-1 and Figure A.2-2 in Appendix A demonstrate [

]

4.2 Single Fuel Assembly Model

The applicability of the single fuel assembly model, as defined in Section 5.2.1 of ANP-10337P-A, to the NuScale fuel design is addressed in this section. This section shows the ability of a benchmarked fuel assembly model to replicate a frequency that characterizes test data from free and forced vibration testing.

The free vibration test is performed in order to characterize the primary, or first mode, natural frequency of the fuel assembly. The NuScale fuel assembly was tested over a range of deflections from [

] For the non-

irradiated (BOL) assembly, the frequency ranges from a [ ] Likewise, the simulated-irradiated (EOL) assembly frequency ranges from a [ ] The EOL condition is more representative of the bulk of the fuel in the NuScale core at any given time, other than the initial startup.

The forced vibration test provides complementary information to the free vibration test by providing a measurement of natural frequencies at higher modes, as well as the primary frequency, albeit, at smaller deflection amplitudes. For the NuScale fuel assembly, the forced vibration test indicates [ ]

Individual BOL and EOL single fuel assembly models are benchmarked to match [ ] following the process defined in Section 6.1.1 of ANP-10337P-A. Table A.3-1 and Table A.3-2 in Appendix A of this report demonstrate that the resulting single fuel assembly models are capable of replicating [ ] measured from the fuel assembly dynamic testing with negligible errors. Therefore, the single fuel assembly model described in Section 5.2.1 of ANP-10337P-A is applicable to the NuScale fuel design.

5.0 NuScale Damping Characteristics

During an external excitation (seismic or LOCA), a PWR fuel assembly experiences the following three sources of energy dissipation when in-core:

- In-air, structural damping. This loss of energy is related primarily to the energy dissipation at the contact interface between fuel assembly components, including the boundary conditions, and is measured in air.
- Quiescent, viscous water damping. This loss is due to irrecoverable pressure losses during the movement of the fuel assembly through water.
- Axial coolant flow damping. This energy dissipation source is related to the hydrofoil effect observed with lateral structural motions in axial flow conditions.

These sources of damping are quantified for the NuScale fuel design in both the non-irradiated and irradiated conditions to replace the generic damping values defined in Section 6.1.3 of ANP-10337P-A.

5.1 Definition of NuScale Damping Values

The different sources of damping can be independently measured by performing free vibration and forced vibration tests on fuel assemblies in air and in water. For NuScale, these sources of damping are based on in-air tests performed on NuScale prototype fuel assemblies, and four additional in-water tests performed on geometrically similar fuel assemblies. Analytical formulations are used to extend in-water test results to the NuScale fuel design.

The final value for the damping ratio of the NuScale fuel assembly is based on the following two components: in-air, structural damping and quiescent, viscous water damping. Each of these components is addressed in more detail below.

In-air, structural damping. The damping ratio is calculated using the free vibration and forced vibration tests that were performed on NuScale non-irradiated and simulated-irradiated fuel assemblies. [

]

[

]

Quiescent, viscous water damping (drag). Data from in-water tests performed on assemblies that have the same cross-sectional geometry as the NuScale fuel design are used to derive the damping ratio value of the NuScale fuel assembly for in-water

conditions (zero flow). [

]

[ ]

[

]

Applying this approach, the in-water damping ratio component [

] These values are based on experiments performed at [
].

The methodology used to establish damping values for the NuScale fuel assembly does not credit the effect of flowing water. This conservatism in the method has been quantified using the same method applied for the quiescent water damping and can be shown to under-represent the damping ratio. Specifically, this component can be shown to [

]

[

]

5.2 Summary of NuScale Damping Values

A summary of the damping ratio values [ ] is given in Table 5-1. [ ]

Table 5-1. Summary of NuScale fuel assembly damping ratios

[ ]

Table 5-2. Summary of NuScale fuel assembly damping ratios for the RFT at 70°F

[ ]

The damping ratio for the NuScale fuel assembly can be dependent on the amplitude at which the fuel assembly is oscillating. In general, the quiescent water damping tends to increase with amplitude while the in-air damping component is non-linear. [ ]

[

]

6.0 Summary and Conclusions

ANP-10337P-A defines a generic methodology for performing the evaluation of the fuel assembly structural response to externally-applied forces (i.e., seismic and LOCA) that is generically applicable to all PWRs. This methodology is applicable to the NuScale design with the following modifications:

- The methodology uses NuScale specific fuel assembly damping values. This modification has been defined and justified within this report.
- In addition to the evaluation of the fuel during operation in the reactor, the NuScale analysis includes a seismic evaluation in which the core is residing in the RFT during refueling operations.

With this modification, ANP-10337P-A is applicable to the NuScale fuel design.

7.0 References

7.0-1 AREVA Inc., “PWR Fuel Assembly Structural Response to Externally Applied Dynamic Excitations,” ANP-10337P-A Rev. 0, April 2018.

7.0-2 U.S. Nuclear Regulatory Commission, “Standard Review Plan, Fuel System Design,” NUREG-0800, Chapter 4, Section 4.2, Rev. 3, March 2007.

7.0-3 ANP-3712P-000, Framatome Responses to NRC RAI No. 9555 regarding NuScale Topical Report TR-0816-51127.

7.0-4 ANP-3591P, Revision 0, AREVA Responses to NRC RAI 8736 (Questions 29611, 29613-29616) regarding TR-0716-50351, “NuScale Applicability of AREVA Method for the Evaluation of Fuel Assembly Structural Response to Externally Applied Forces.”

Appendix A. Review of NuScale Fuel Characterization Test Data Applicability to ANP-10337P-A

A.1 Introduction

The purpose of this appendix is to provide a review of NuScale fuel characterization test data in order to demonstrate the behavior necessary to confirm the applicability of ANP-10337P-A. Specifically, Section 2.2 of ANP-10337P-A requires an explicit demonstration of the applicability of grid impact modeling elements. In addition, Section 3.3 of this report notes that the NuScale fuel assembly is outside the range of typical PWR designs to which ANP-10337P-A is applied in terms of both overall fuel assembly length and the number of spacer grids. This appendix also demonstrates the application of the single fuel assembly model described in Section 5.2.1 of ANP-10337P-A to the NuScale design, with a shorter overall length and fewer spacer grids.

A.2 Spacer Grid Behavior

Under lateral impacts over the range of application, Section 2.2 of ANP-10337P-A specifies that [

]

The NuScale fuel design utilizes the same 17x17 HTP™ spacer grid that is currently in use in operating plants. Thus, this behavior is well established for this existing grid design. The data to be reviewed here are generic and not specific to NuScale.

Figure A.2-1 and Figure A.2-2 demonstrate [

] Figure A.2-1 and Figure A.2-2 present this relationship for single grids, but they are representative of the same behavior seen over the total population of tested spacer grids. [

]

[

]

Figure A.2-1. [
]

[

]

Figure A.2-2. [
]

A.3 Single Fuel Assembly Model

The applicability of the single fuel assembly model, as defined in Section 5.2.1 of ANP-10337P-A, to the NuScale fuel design is addressed in this section. The desired

result from this demonstration is to show the ability of a benchmarked fuel assembly model to replicate a frequency that characterizes test data from free vibration and forced vibration testing.

The cross-sectional geometry of the NuScale fuel design is the same as that of other designs that are currently operating. The only unique characteristics of the NuScale fuel design are its shorter length and fewer spacer grids.

The NuScale fuel assembly was subjected to the program of characterization testing as summarized in Table 6-4 of ANP-10337P-A. The free vibration and forced vibration tests are of particular importance to the creation of a lateral single fuel assembly model. These tests provide information regarding the natural frequencies of the fuel assembly. A plot of first mode frequency versus deflection amplitude from free vibration testing is presented for non-irradiated (BOL) and simulated-irradiated (EOL) assemblies in Figure A.3-1.

Figure A.3-1. NuScale fuel assembly first-mode frequency versus deflection amplitude, non-irradiated (BOL) and simulated-irradiated (EOL), ambient conditions

As can be seen from Figure A.3-1, the NuScale fuel assembly was tested [

] For the BOL assembly, the frequency ranges from a [

]

In comparison to the BOL assembly behavior, the EOL assembly [
] Furthermore, the EOL condition is more representative of the bulk of the fuel in the NuScale core at any given time, other than the initial startup. For the EOL assembly, the frequency ranges from [

]

The establishment of the mid-point frequency as the benchmark target is consistent with the process illustrated in Figure 6-1 of ANP-10337P-A. The deflection amplitudes corresponding to the BOL and EOL mid-point frequencies are different, but the mid-point frequency results in a more representative characterization of the fuel assembly natural frequency.

Forced vibration testing was also performed on the NuScale fuel assembly. This testing was performed at deflection amplitudes that were smaller than those tested in free vibration, due to the large amount of energy required to simultaneously excite multiple modes of the fuel assembly. However, while the free vibration test only provides a measurement of the first mode frequency, the forced vibration testing provides a measurement of natural frequencies at higher modes, as well as the primary frequency. Specifically, the forced vibration testing demonstrated [

]

Individual BOL and EOL single fuel assembly models were benchmarked to match [
] following the process defined in Section 6.1.1 of ANP-10337P-A. The results of the benchmarking process are presented in Table A.3-1 and Table A.3-2.

Table A.3-1. NuScale fuel assembly frequency benchmark results, non-irradiated condition

[ ]

Table A.3-2. NuScale fuel assembly frequency benchmark results, simulated-irradiated condition

[ ]

Table A.3-1 and Table A.3-2 demonstrate that the resulting single fuel assembly models are capable of replicating [ ] measured from the fuel assembly dynamic testing with negligible errors. Therefore, the single fuel assembly model described in Section 5.2.1 of ANP-10337P-A is applicable to the NuScale fuel design.

A.4 Conclusions / Summary

This appendix has demonstrated the applicability of both the grid impact model and the fuel assembly dynamic model from ANP-10337P-A to the NuScale fuel design.

Appendix B. NuScale Damping for Lateral Accident Condition Analysis

B.1 Introduction

During an external excitation (seismic or LOCA), a PWR fuel assembly experiences the following three sources of energy dissipation:

- In-air, structural damping. This loss of energy is related primarily to the energy dissipation at the contact interface between fuel assembly components, including the boundary conditions, and is measured in air.
- Quiescent, viscous water damping. This loss is due to irrecoverable pressure losses during the movement of the fuel assembly through water.
- Axial coolant flow damping. This energy dissipation source is related to the hydrofoil effect observed with lateral structural motions in axial flow conditions.

This appendix determines these damping ratio values for the NuScale fuel design in both the non-irradiated and irradiated conditions.

B.2 Methodology

The different sources of damping can be independently measured by performing free vibration and forced vibration tests on fuel assemblies in air and in water. For NuScale, these sources of damping are based on in-air tests performed on NuScale prototype fuel assemblies and in-water tests performed on fuel assemblies that have the same cross-sectional geometry. Analytical formulations are used to extend in-water test results to the NuScale fuel design.

A broad set of experimental datasets are used to establish damping ratios for the NuScale fuel assemblies. A description of these experiments is provided below:

- The NuScale tests involve two NuScale 17x17 prototype fuel assemblies with HTP™ spacer grids (non-irradiated and simulated-irradiated) subjected to free vibration and forced vibration tests in air. The results from these tests provide a direct measurement of in-air, structural damping ratios for NuScale fuel.
- The MASSE tests were performed using [ ] Both free vibration and forced vibration tests were performed in both air and water, including the effects of flowing water. These tests are used to support the in-water damping ratio of the NuScale fuel assembly in the non-irradiated condition.
- The CAMEOL tests were performed using [ ] Forced vibration tests were performed in both air and water, including the effects of flowing water.

These tests are used to support the in-water damping ratio of the NuScale fuel assembly in the irradiated condition.

- The MALDIVE tests were performed using [

  ] Both free vibration and forced vibration tests were performed in both air and water, including the effects of flowing water.

- The MARITIME tests were performed using [

  ] Both free vibration and forced vibration tests were performed in air. These test results were reviewed to provide additional insight on the structural damping ratios of short assemblies and validate the NuScale fuel assembly damping ratios.

The final value for the damping ratio of the NuScale fuel assembly is based on the following two components, and the method used to quantify these components is provided:

- In-air, structural damping. The damping ratio is calculated using the free vibration and forced vibration tests that were performed on NuScale non-irradiated and simulated-irradiated fuel assemblies. [

  ]

- Quiescent, viscous water damping (drag). [

  ,]

[ ]

where

[

]

The methodology used to derive damping for the NuScale fuel assembly does not credit the effect of flowing water. This conservatism in the method has been quantified and can be shown to under-represent the damping ratio of the fuel by more than [

]

The damping ratio for the NuScale fuel assembly can be dependent on the amplitude at which the fuel assembly is oscillating. [

]

[

]

B.3 Results

B.3.1 Structural damping ratio

The structural damping ratio measured from the experiment for the NuScale fuel assembly (BOL and EOL) is shown in Figure B.3-1.

[ ]

Figure B.3-1. Experimental damping ratio values for mode 1 for the non-irradiated and simulated-irradiated NuScale fuel assembly (in-air, free vibration tests)

[ ]

[ ]

[ ]

[ ]

[

]

[ ]

B.3.2 Quiescient, viscous water damping (zero flow)

Through the experimental campaigns defined in Section B.2, it has been demonstrated that when a fuel assembly is immersed in water and is subjected to an external excitation, an additive damping component can be measured due to the movement of the fuel through a dense fluid. This additional damping component will increase with an increase in the amplitude of oscillation.

[

]

[ ]

[

]

[

]

[ ]

[

]

[ ]

B.3.3 Axial Coolant Flow Damping

Beyond the damping components discussed thus far, there is an additional source of damping that is associated with the axial flow of coolant past the bundle. This additional damping has been demonstrated through numerous experimental campaigns and can be quantified for NuScale. Using the MASSE, CAMEOL, and MALDIVE test data, and the same method employed in Section B.3.2, a damping ratio can be quantified for the NuScale flow conditions. This component can [

] However, for conservatism, the effects of coolant flow will not be credited in the total damping ratio for the NuScale fuel assembly.

B.4 Summary of Fuel Assembly Damping Ratios for NuScale

A summary of the damping ratio values [
] is given in Table B.4-1. [

]

Table B.4-1. Summary of NuScale fuel assembly damping ratios

[ ]

Table B.4-2. Summary of NuScale fuel assembly damping ratios for the RFT at 70°F

[ ]

[ ]

[

]

Enclosure 3:

Affidavit of Gayle Elliott, Framatome, Inc.

AFFIDAVIT

1. My name is Gayle Elliott. I am Deputy Director, 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 Licensing Topical Report TR-0716-50351-P, Revision 1, entitled "NuScale Applicability of AREVA Method for the Evaluation of Fuel Assembly Structural Response to Externally Applied Forces," dated December 2019, 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 paragraphs 6(d) and 6(e) 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.

Gayle Elliott

Commonwealth of Virginia)
) ss.
City of Lynchburg)

SUBSCRIBED before me this 17 day of December, 2019.

Heidi Hamilton Elder

Heidi Elder
NOTARY PUBLIC, COMMONWEALTH OF VIRGINIA
MY COMMISSION EXPIRES: 12/31/22
Reg. # 7777873

HEIDI HAMILTON ELDER
COMMONWEALTH
REGISTRATION NO. 7777873
MY COMM. EXPIRES 12/31/2022
OF VIRGINIA
NOTARY PUBLIC