FINAL SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

ANP-10337P, REVISION 0,

"PWR FUEL ASSEMBLY STRUCTURAL RESPONSE TO EXTERNALLY APPLIED DYNAMIC EXCITATIONS"

FRAMATOME INC,

DOCKET NO. 99902041

1.0 INTRODUCTION

By letter dated August 31, 2015 (Reference 1), as supplemented by a letter dated October 20, 2017 (Reference 2), Framatome Inc. (Framatome, formerly AREVA Inc.) requested review and approval of Topical Report (TR) ANP-10337P, "PWR Fuel Assembly Structural Response to Externally Applied Dynamic Excitations." This TR presents a generic methodology to evaluate the structural response of pressurized water reactor (PWR) fuel assembly designs subjected to dynamic loads under seismic and loss-of-coolant accident (LOCA) events. The methodology is used to develop analytical models to describe the structural response of fuel assemblies in the horizontal and vertical directions. These structural response results are evaluated to satisfy the criteria defined in the U.S. Nuclear Regulatory Commission's (NRC) regulations, specifically Title 10 of the *Code of Federal Regulations* (10 CFR), Part 50, Appendices A and S.

ANP-10337P documents:

- the development, benchmarking, and implementation of analytical models to represent the fuel assembly structural response,

- the protocol used for benchmark testing, and

- the acceptance criteria used to meet regulatory requirements.

The revised methodology addresses issues raised in NRC Information Notice 2012-09 (Reference 3). Furthermore, this TR consolidates and updates the methodology described in BAW-10133-P(A) incorporating the following advancements:

- definition of methodology for evaluating fuel in the irradiated condition, including the effect on spacer grid structural response as well as the overall fuel assembly,

- definition of the spacer grid allowable impact load both in the irradiated and nonirradiated condition,

- update of the protocol for benchmarking fuel assembly dynamic characteristics from tests,

- update of the methodology for calculating non-grid component loads and stresses,

- update of the acceptance criteria for guide tube stresses under LOCA and Safe Shutdown Earthquake (SSE),

- clarification of the description of the numerical model for vertical load analysis,

- clarification of the methodology for combining loads from the horizontal and vertical analyses,

- implementation of Rayleigh or generalized proportional damping in the analysis models, and

- augmentation of the basis for fuel assembly damping in the horizontal direction due to the changes in bundle frequency due to irradiation.

The NRC staff's review was assisted by Pacific Northwest National Laboratory (PNNL). The NRC staff's conclusions on the acceptability of ANP-10337P are supported by PNNL's Technical Evaluation Report (Reference 7).

To support its review of ANP-10337P, the NRC staff conducted an audit at the Framatome facilities in Lynchburg, Virginia during May and September 2017. The NRC staff's audit report (Reference 4) documents the objectives and findings of this audit.

2.0 REGULATORY EVALUATION

Regulatory guidance for the review of fuel system materials and designs and adherence to General Design Criteria (GDC)-10, GDC-27, and GDC-35 is provided in NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants" (SRP), Section 4.2, "Fuel System Design" (Reference 5). In accordance with SRP Section 4.2, the objectives of the fuel system safety review are to provide assurance that:

- The fuel system is not damaged as a result of normal operation and anticipated operational occurrences (AOOs),

- Fuel system damage is never so severe as to prevent control rod insertion when it is required,

- The number of fuel rod failures is not underestimated for postulated accidents, and

- Coolability is always maintained.

With respect to fuel performance under seismic and combined loads, GDC-2, "Design bases for protection against natural phenomena," requires the following:

> Structures, systems, and components important to safety shall be designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, floods, tsunami, and seiches without loss of capability to perform their safety functions. The design bases for these structures, systems, and components shall reflect:
> (1) Appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for the

> limited accuracy, quantity, and period of time in which the historical data have been accumulated, (2) appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena, and (3) the importance of the safety functions to be performed.

This GDC requires safety-related structures, systems, and components (SSCs), including reactor fuel, to be designed to withstand natural phenomena such as earthquakes without a loss of capability to perform safety functions. This GDC also requires an appropriate combination of the effects of normal and accident conditions with the effects of the natural phenomenon.

Appendix S of 10 CFR Part 50 implements GDC-2 as it pertains to seismic events, and defines specific earthquake engineering criteria for nuclear power plants. This appendix establishes definitions for the SSE, Operating Basis Earthquake (OBE), and safety requirements for relevant SSCs. These SSCs must assure the integrity of the reactor coolant boundary, the capability to shut down the reactor and maintain it in a safe-shutdown condition, and the capability to prevent or mitigate the consequences of accidents that could result in potential offsite exposures.

Appendix S(IV)(a)(2) states the following OBE functional requirements:

> (I) When subjected to the effects of the Operating Basis Earthquake Ground Motion in combination with normal operating loads, all structures, systems, and components of the nuclear power plant necessary for continued operation without undue risk to the health and safety of the public must remain functional and within applicable stress, strain, and deformation limits.

According to Appendix S, all SSCs necessary for continued operation without undue risk to the health and safety of the public, including reactor fuel, must be designed to withstand OBE loads combined with normal operating loads. For each SSC, stress, strain, and/or deformation limits should be defined to ensure functional capabilities.

With respect to SSE functional requirements, Appendix S(IV)(a)(1) states the following:

> (ii) The nuclear power plant must be designed so that, if the Safe Shutdown Earthquake Ground Motion occurs, certain structures, systems, and components will remain functional and within applicable stress, strain, and deformation limits. In addition to seismic loads, applicable concurrent normal operating, functional, and accident-induced loads must be taken into account in the design of these safety-related structures, systems, and components.

According to Appendix S, safety-related SSCs, including reactor fuel, must be designed to withstand SSE loads combined with concurrent normal operating, functional, and accident-induced loads. In other words, safety-related SSCs must perform their intended function when exposed to the combined loads of SSE ground motion in combination with functional and accident loads (during the accident for which the SSC is designed to mitigate). For each safety-related SSC, stress, strain, and/or deformation limits should be defined to ensure functional capabilities.

Section 3 of ANP-10337P describes the regulatory requirements associated with fuel assembly performance under seismic and LOCA applied loads. Section 4 of ANP-10337P defines fuel assembly component-specific acceptance criteria which satisfy OBE, SSE, and combined LOCA+SSE (or LOCA alone) functional requirements. During the audit, the NRC and Framatome staffs discussed the regulatory requirements and associated acceptance criteria. As a result of these discussions, revisions were made to Section 3 and 4 of ANP-10337P (See Section 22 of Reference 2). These issues are described below.

OBE Requirements

Section 4.1 of ANP-10337P describes the acceptance criteria used to demonstrate compliance with OBE regulatory requirements. With the exception of the spacer grid, Framatome proposes an acceptance criterion based on American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME BPVC) Level B stress limits. This is standard practice and therefore acceptable. More specific criteria for non-grid components may be specified in other TRs covering the analysis of these fuel assembly components at normal operation.

For the spacer grid, the limit on grid impact force corresponds to **[** **]** ensures that the functional requirements of the grid (e.g. control rod insertion, fuel rod spacing) are maintained.

Based upon the above discussions, the NRC staff finds that the acceptance criteria defined in ANP-10337P satisfy the regulatory requirements for OBE. Further discussion on the technical adequacy of these acceptance criteria is provided in Section 3.2.

SSE Requirements

Section 4.3 of ANP-10337P describes the acceptance criteria used to demonstrate compliance with SSE regulatory requirements. The SSE is a design basis natural phenomenon which the plant must withstand without a loss of capability to perform safety functions.

Existing regulatory guidance does not clearly stipulate an acceptable means for compliance to 10 CFR Part 50, Appendix A, GDC-2 and Appendix S requirements with respect to fuel performance during a SSE and how its performance relates back to functional requirements for safety-related SSCs. This has led to a difference between the industry and the NRC staff regarding the interpretation of regulations regarding fuel assembly grid deformation under SSE-only loads.

Historically this would not have been a problem since there was no expectation of fuel assembly grid deformation under SSE-only loads. However, evolutionary changes in fuel mechanical design and materials (designed to increase thermal-hydraulic performance) have resulted in grids which are structurally weaker and/or more likely to exhibit greater plastic deformation before buckling. Another contributing factor is the desire by some fuel vendors to globally market a single fuel assembly design based on worst-case combinations of seismic conditions. Furthermore, Information Notice 2012-09 identified negative impacts associated with irradiation on grid crush strength which were not previously considered during fuel assembly structural response analyses.

During the audit, the NRC and Framatome staffs discussed SSE requirements. Framatome's position was that the functional capability of safety-related SSCs is assured via the following fuel assembly design requirements:

- **[** **]**.
- **[** **]**.
- **[** **]**.
- **[** **]**

The NRC staff accepts Framatome's design requirements as they relate to demonstrating the functional capability for each fuel assembly component. However, the NRC staff questioned whether Framatome fully addressed all of the Appendix S requirements. Of particular concern:

- Any significant grid deformation under SSE motion may alter the local thermal-hydraulic conditions and potentially creates an unanalyzed condition relative to the demonstrated performance of safety-related SSCs to perform their intended function. Performance being both functional capability and timing of action.

- Any significant grid deformation under SSE motion may cause friction between the control rods and guide tubes and delay scram insertion. This potentially creates an unanalyzed condition relative to the demonstrated performance of safety-related SSCs to perform their intended function.

For AOOs and non-LOCA accidents, reactor protection system and engineered safety features actuation system actions and the timing of these actions are essential to assure the integrity of the reactor coolant boundary, the capability to shut down the reactor and maintain it in a safe-shutdown condition, and the capability to prevent or mitigate the consequences of accidents that could result in potential offsite exposures. If grid deformation impacts local thermal-hydraulic conditions (e.g., reduction in rod pitch, coolant flow area) such that the magnitude or rate of change in departure from nucleate boiling (DNB) degradation changes, then the demonstrated performance of safety-related SSC to perform their intended function may be impacted. Likewise, if grid deformation delays control rod scram insertion such that the magnitude of DNB degradation changes, then the demonstrated performance of safety-related SSC to perform their intended function may be impacted. Any delay in control rod scram insertion may also impact predicted margin to other specified acceptable fuel design limits (SAFDLs) (e.g., fuel cladding strain, fuel melt) and margin to system pressure design limits and further challenge the performance of safety-related SSC to perform their intended function.

In response to a request for additional information (RAI) question regarding allowable permanent grid deformation (RAI 15, Reference 2), Framatome defined and provided justification for a maximum allowable permanent grid deformation under SSE loads. As described in its response, **[** **]**. Following discussions with the NRC staff, Table 4-1 acceptance criteria were further revised to clarify that the load limit must also remain below the **[** **]**. Change pages to ANP-10337P are included in the RAI response (Reference 2).

The technical justification and the NRC staff review of the allowable permanent grid deformation is described in Section 3.2 of this SE.

Another concern revolves around the use of stress-based criteria to ensure operability. ANP-10337P proposes a stress-based criterion to be applied to guide tubes and the guide tube connection to the top nozzle to ensure control rod insertion. The normal American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Committee (BPVC) code interpretation is that all components, including guide tubes and their connections, are subject to Level D service limits to meet structural requirements. Level D permits gross deformation of structures but prohibits structural failure. All ASME BPVC limits are structural limits; they are not defined to maintain operability. Framatome has proposed a reduction in allowable stress to Service Level C. The technical justification and NRC staff review of the use of **[ ]** to ensure guide tube integrity and control rod insertion are described in Section 3.2.

Based upon the above discussions, the NRC staff finds that the acceptance criteria defined in ANP-10337P as amended by RAI 15 satisfy the regulatory requirements for SSE.

<u>LOCA or Combined LOCA+SSE Requirements</u>

Section 4.2 of ANP-10337P describes the acceptance criteria used to demonstrate compliance with LOCA regulatory requirements. Specifically,

- Fuel rod fragmentation does not occur as a result of the blowdown loads
- Control rod insertability is assured, if required
- 10 CFR 50.46 temperature and oxidation limits are not exceeded

It should be noted that control rod insertion is required for SSE and may be required for certain LOCA scenarios.

During the audit, the NRC and Framatome staffs discussed LOCA and combined LOCA+SSE requirements. Framatome originally proposed the following fuel assembly design requirements:

- **[ ]**
- **[ ]**
- **[ ]**
- **[ ]**

Section 4.2.1 of ANP-10337P describes **[**

]

In response to an RAI regarding allowable permanent grid deformation (RAI 15, Reference 2), Framatome defined and provided justification for a maximum allowable permanent grid deformation under LOCA or combined LOCA+SSE loads. As described in the response, **[**

]. In addition, the Appendix E analytical approach was removed. Following discussions with the NRC staff, Table 4-1 acceptance criteria were further revised to clarify that **[**
]. Change pages to ANP-10337P are included in the RAI response (Reference 2). The technical justification and the NRC staff review of the allowable permanent grid deformation are described in Section 3.2.

Another concern revolves around the use of stress-based criteria to ensure operability. ANP-10337P proposes a stress-based criterion to be applied to guide tubes and the guide tube connection to the top nozzle to ensure control rod insertion. The normal ASME BPVC code interpretation is that all components, including guide tubes and their connections, are subject to Level D service limits to meet structural requirements. Level D permits gross deformation of structures but prohibits structural failure. All ASME BPVC limits are structural limits; they are not defined to maintain operability. Framatome has proposed a reduction in allowable stress to Service Level C. The technical justification and staff review of the use of ASME BPVC Service Level C stress limits to ensure guide tube integrity and control rod insertion are also described in Section 3.2.

Based upon the above discussions, the NRC staff finds that the acceptance criteria defined in ANP-10337P as amended by RAI 15 satisfy the regulatory requirements for LOCA and combined LOCA+SSE.

<u>Additional Changes for Sections 3 and 4 of ANP-10337P</u>

During the audit, the NRC staff identified that some licensees may remain licensed under 10 CFR Part 100 instead of Appendix S. Section 3.1 was amended.

As described above, the SSE requirements and acceptance criteria were revised. As a result, discussions associated with dose consequences were removed from Section 3.1.2.

The sentence “Accident induced load conditions caused by seismic events will be accounted” does not appear in Appendix S and was removed from Section 3.1.2.

Section 3.1.4 contained the sentence: “Furthermore, by establishing conservative criteria that prevents fuel rod fragmentation, this conservatively addresses the requirements regarding the radiological consequences of design basis accidents (i.e. 10 CFR 100, 10 CFR 50.34, 10 CFR 50.67).” Preventing fuel rod fragmentation alone does not ensure integrity of the cladding fission product barrier under all AOO and accident conditions. As described above, impacts to local thermal-hydraulic conditions and scram insertion timing due to grid spacer deformation may impact predicted DNB degradation. This sentence was removed from Section 3.1.4.

Section 4.3 of ANP-10337P originally stated:

> As the resulting criteria to demonstrate control rod insertion and fuel rod fragmentation are the same as that for the combined LOCA and SSE evaluation, an SSE-only evaluation is only necessary in cases where the licensing basis for the host plant does not require an analysis for combined loads.

The NRC staff does not accept the stated position. Licensees are always required to address SSE requirements and demonstrate safety-related SCC functionality under a wide range of AOO and accident conditions. Given that the acceptance criteria for combined LOCA+SSE may not always bound SSE-only, this statement is misleading. In the past, licensees demonstrated that the predicted combined LOCA+SSE loads remained below measured grid cage buckling loads. For these past designs and analytical methods, grid spacers experienced an insignificant amount of plastic deformation prior to buckling. In this situation, the grid spacer acceptance criterion is satisfied for both SSE-only and combined LOCA+SSE. However, once grid spacer acceptance criteria are based on allowable permanent deformation, combined LOCA+SSE may not always bound SSE-only. For combined LOCA+SSE loads, grid spacer acceptance criteria may be governed by the limiting of the following factors:

- Control rod insertion
- Compliance to 10 CFR 50.46 PCT and maximum local oxidation analytical limits
- Buckling

For SSE-only, grid spacer acceptance criteria may be further restricted by potential impacts on DNB calculations and scram insertion timing which are likely more sensitive to allowable permanent deformation. In addition, radiological consequences must be considered. For SSE-only conditions, there is no expectation of fuel rod cladding failure (i.e., failure of fission product barrier and release of fission gas) and no specific offsite dose calculations. Whereas, for LOCA, there is no expectation of fuel rod cladding integrity and offsite dose calculations are based on an assumption of significant core damage (e.g., Table 1 and 2 of Regulatory Guide (RG) 1.183). Hence, LOCA acceptance criteria (which preserve a coolable core geometry, but not cladding integrity) do not necessarily bound fuel performance requirements for SSE-only.

To bound or simplify the seismic design analysis, the licensee may elect to apply the combined LOCA+SSE loads to the most limiting component of the SSE-only and LOCA+SSE allowable grid permanent deformations.

Based on the above discussion, the sentence was removed from Section 4.3 of ANP-10337P.

3.0 TECHNICAL EVALUATION

The purpose of ANP-10337P is to define a generic modeling and analysis methodology to describe the structural response of PWR fuel assemblies in the horizontal and vertical directions. The methodology defined in ANP-10337P is an update of an analysis methodology that was previously defined in BAW-10133P-A and its Addenda 1 and 2 (Reference 6). The analysis methodology of ANP-10337P includes finite element models, instructions on how to define the finite element models from test data, instructions on how to interpret the finite element model results, and acceptance criteria that the results of the finite element models are to be compared against to demonstrate that the design bases are met. ANP-10337P also includes descriptions of the mechanical testing required, assumptions related to the methodology, and built-in limitations of the fuel assembly behavior.

The NRC staff's review was assisted by structural analysis and finite element analysis experts from PNNL in Richland, Washington. Reference 7 provides a portion of the technical bases for the NRC staff's review and approval.

3.1 Range of Applicability

Section 2 of ANP-10337P addresses the range of applicability of the fuel seismic design methodology. In Section 2.1, the basic design attributes of PWR fuel assembly components are described. Table 2-1 details the configuration of PWR fuel assembly designs for the existing Combustion Engineering, Inc. (CE), Westinghouse Electric Company (Westinghouse), and Babcock & Wilcox Company reactor types. Framatome's intent is that the seismic methodology be applicable to any PWR fuel assembly design and any reactor core design. This is evident from the following text:

> This TR is generically applicable to PWR fuel assembly designs. As discussed in Section 2.1, PWR fuel designs exhibit a similar geometry and structure that is appropriately represented by the modeling architecture defined in this TR (Section 5.0). However, the actual numerical values used to define the structural characteristics of a given fuel assembly will vary from one design to another. This level of design specificity is incorporated into the methodology through the testing and model benchmarking processes defined in Section 6.0. Therefore, this methodology is applicable to any fuel assembly geometry that can be characterized by the testing and model benchmarking processes defined in this topical. Furthermore, this methodology can be applied to any reactor core geometry for which the seismic and LOCA boundary conditions can be defined. As such, the specifics of the fuel and reactor core geometry are unimportant in defining the generic methodology, but they are an important parameter in the application of the methodology to a specific fuel design and reactor.

In general, the NRC staff agrees with this assertion. However, future PWR fuel assembly designs may contain different geometries, materials, or structures which challenge the underlying seismic analytical modelling approach and/or testing protocols. Furthermore, design and/or material changes may also dramatically change the response of the assembly components to externally applied loads. Section 3.2 defines a limitation and condition (L&C) on the NRC staff's approval related to changes to fuel assembly design and materials.

Section 2.2 of ANP-10337P describes characteristics of the spacer grid's response to external loads which are inherent in the methodology. This limit on the applicability of the seismic methodology is provided below:

> **[**
>
> **]** In this case, the methodology can be shown to appropriately predict peak impact loads and rebound velocity.

Aside from the [ ] behavior of the spacer grid, no other performance related restrictions are identified. However, Section 4.2.1 of ANP-10337P describes an additional specific spacer grid performance characteristic inherent in the underlying methodology.

[ ]

L&C #1 captures a limit on the range of application of the ANP-10337P methodology based upon the spacer grids performance during the dynamic grid crush testing.

L&C #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. [ ].

L&Cs #4, #5, and #9 also contain limits on the range of applicability.

3.2 Acceptance Criteria

Section 3 correlates the acceptance criteria within Section 4 of ANP-10337P to the regulatory requirements. The purpose of this section is to review the proposed acceptance criteria on their technical merits.

3.2.1 Grid Impact Force Acceptance Criteria

ANP-10337P proposes spacer grid impact force acceptance criteria based upon mechanical (grid crush) testing at beginning of life (BOL) and simulated end of life (EOL) conditions. The specific acceptance criterion at each time-in-life is [ ]. The technical assessment of the grid cage impact force acceptance criteria is provided in Section 6.2 of Reference 7.

Framatome proposing to allow grid strength [ ] was a concern. In response to an RAI regarding this concern (RAI 11, Reference 2), Framatome stated that the methodology did not support [ ]. The response was acceptable because the methodology uses a [ ].

Appendix D on ANP-10337P describes the testing protocol to simulate EOL conditions using non-irradiated spacer grids. Data from previous testing on irradiated spacer grids are used to justify the experimental protocols. The difference between irradiated material and non-irradiated material behavior, and the effect it would have on the grid test data was of concern. During an audit, proprietary reports were reviewed that contained material property data and additional irradiated grid test data. The material in Appendix D and the proprietary information reviewed at the audit form a compelling argument that supports the use of the **[ ]**.

The amount of grid spring relaxation that is prescribed by the methodology for testing was concerning. In response to an RAI regarding grid relaxation (RAI 14, Reference 2), Framatome described how the **[ ]**. The RAI response is acceptable because it generally defines what is to be done. This is a typical kind of technical detail that would be reviewed at the discretion of technical reviewers on a case-by-case basis.

The reduction in ductility with irradiation hardening **[ ]**. During an audit, Framatome described the residual ductility measured in the irradiated spacer grid tests, including those described in Appendix D. In addition, an independent finite element analysis was completed. See Section 6.2.3 of Reference 7 for further information.

The simulated EOL grid test protocol is concluded acceptable for use in this methodology based on the technical information provided in Appendix D, the proprietary documents reviewed at the NRC staff audit, Framatome's response to RAI 14, the independent finite element modeling, L&C #1, and L&C #4.

3.2.1.1 Allowable Grid Uniform Permanent Deformation Limits

It is important to note that the allowable deformation described below is related to the structural and functional requirements of the spacer grid (e.g. control rod insertion, fuel rod spacing). Section 3.3 described a separate limit of permanent grid deformation related to the analytical methodology.

For OBE, the spacer grid impact force corresponds to an allowable deformation within design tolerances. Maintaining dimensions within design tolerances ensures that the functional requirements of the grid are maintained. There is no challenge to control rod insertion and fuel rod spacing is not impacted. Furthermore, given that the applicability of ANP-10337P is limited to spacer grids which **[ ]**.

In response to an RAI regarding allowable permanent grid deformation (RAI 15, Reference 2), Framatome defined and provided justification for a maximum allowable permanent grid deformation under SSE, LOCA, or combined LOCA+SSE loads. As described in the response, **[ ]** was proposed. The technical basis for the allowable grid deformation is summarized below:

- For SSE-only loads, this allowable deformation has been shown to have a negligible effect on calculated MDNR during AOO conditions.

- For combined LOCA+SSE or LOCA-only loads, this allowable deformation has been shown to have a negligible effect on calculated PCT under LOCA conditions.

As described in the audit report (Reference 4), the NRC staff reviewed the underlying Framatome engineering calculations which quantified the potential impact of a **[ ]** on calculated DNB ratio (DNBR) under a wide range of transient conditions. Results of these calculations are presented in RAI 15 response and show a negligible change in calculated DNBR under a wide range of transient conditions for multiple fuel assembly lattice designs.

As described in the audit report (Reference 4), the NRC staff reviewed the underlying Framatome engineering calculations which quantified the potential impact of a **[ ]** on calculated PCT under LOCA conditions. The results of this study show a minimal increase in PCT for multiple fuel assembly lattice designs.

No analytical calculations were performed to justify the **[ ]** in the peripheral assemblies, either for ΔDNBR or ΔPCT. During the audit, the NRC staff reviewed reload depletion calculations from a Westinghouse 15x15 plant, a Westinghouse 17x17 plant, and a CE 14x14 plant. The purpose of this investigation was to quantify the reduced power in the peripheral assemblies to reinforce the qualitative arguments used to justify the larger allowable deformation.

Table 3-1 lists the results of the investigation into peripheral fuel assembly power peaking factors. As shown in the table, peripheral fuel assemblies operate at considerably lower power than interior assemblies. This reduced power translates to significantly higher DNB thermal margin during normal operation. Hence, at the start of any postulated transient, these peripheral assemblies would have significantly more DNB margin compared to the limiting, hot rods in the interior of the core. This additional margin would compensate for the reduction in flow area (i.e. rod pitch) associated with the **[ ]**. In other words, the reduction in calculated DNBR during the postulated transient (due to transient changes in local conditions) in combination with any further reduction in calculated DNBR due to the lattice deformation, would not violate the DNBR SAFDL in these lower power peripheral assemblies. The higher power, interior fuel rods would continue to be DNB limiting. Hence, DNB thermal margin requirements and/or predicted number of fuel rod failures would not be impacted by the **[ ]**. Similarly, fuel rods located on the core periphery would operate with considerably lower stored energy and decay heat loads. This translates to lower calculated PCT during a postulated LOCA relative to interior fuel rods. Hence, ECCS performance requirements would continue to be dictated by the higher power, interior fuel rods.

Table 3-1: Peripheral Fuel Assembly Power Peaking Factors

[ ]

Based on the above discussion, the NRC staff finds the allowable spacer grid permanent deformation limits acceptable. L&C #2 captures these limits.

L&C #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 LOCA+SSE analyses, **[** **]**

Based upon the above discussion, the NRC staff finds the spacer grid allowable impact force acceptance criteria and allowable uniform permanent deformation acceptable.

3.2.2 Fuel Assembly Component (Non-Grid) Stress Criteria

The technical assessment of the fuel assembly component (non-grid) acceptance criteria is provided in Section 6.1 of Reference 7. Based on its standard implementation of ASME BPVC and NRC guidance, the use of ASME BPVC Level B service limits under OBE loading conditions was found acceptable for fuel assembly components (non-grid). Under SSE, LOCA, or LOCA+SSE, most non-grid components are evaluated against ASME BPVC Level D service limits. Guide tubes and the connection between the guide tube and top nozzle in control rod core locations are restricted to Level C limits to ensure insertion. Guide tubes are also required to maintain a positive margin against buckling. With the notable exception of the Level C insertion limit, these acceptance limits are acceptable because they are standard implementation of ASME BPVC and NRC guidance.

Appendix E of ANP-10337P demonstrates that limiting guide tube stress to ASME BPVC Level C service limits will assure control rod insertion, with one stress-based acceptance criterion, would cover both structural requirements and control rod insertion acceptance. Framatome performed control rod insertion testing into deformed guide tubes, supported by finite element modeling, to support their justification that control rods are insertable within time constraints in guide tubes that are deformed to Level C limits and beyond.

In response to an RAI regarding the control rod insertion testing (RAI 20, Reference 2), Framatome provided further details of the testing and justification for Service Level C. The additional information supported the Service Level C insertion criterion. An independent modeling study was performed to investigate the Service Level C control rod insertion limit. The goal was to estimate how much residual deflection could occur in a guide tube limited to Level C stress limits. A more aggressive imposed deflection shape was assumed than was considered by Framatome and a simplified guide tube geometry based on a different PWR fuel assembly design was used. The resulting residual deformation state was more challenging than the one Framatome performed insertion tests on, but it is questionable whether that shape could actually occur in a real fuel assembly. The independent modeling generally supports Framatome's test database and Framatome's conclusion that Level C limits ensure insertion.

Future changes in materials, geometry (i.e., dimensions and clearances) or design of either the guide tubes or control rods could affect insertion times and the justification of the Level C criterion. In addition, application of this methodology to new PWR designs with different dimensions and clearances could affect the underlying bases. L&C #4 was developed to limit the application of this methodology (and its underlying bases) to PWR fuel designs and reactor designs similar to the current fleet. Section 6.1.3 of Reference 7 provides further discussion on this L&C.

> **L&C #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.

Framatome's control rod insertion data set supports the use of ASME BPVC Level C basic stress limits as a demonstration of control rod insertion, with L&C #4 to ensure that fuel designs evaluated with this methodology are similar to operational experience.

Based upon the above discussion, the NRC staff finds the fuel assembly component (non-grid) acceptance criteria acceptable.

3.3 Analytical Models and Application Methodology

ANP-10337P defines a set of finite element models that are used to evaluate fuel assembly response to seismic and LOCA excitation. There are three finite element models included in ANP-10337P: 1) a vertical dynamic finite element model of the fuel assembly, 2) a horizontal dynamic finite element model of a row of fuel assemblies, and 3) a three-dimensional (3D) structural model of a fuel assembly's major components. Section 5 of ANP-10337P describes the architecture of the vertical and horizontal finite element models and Section 8 of ANP-10337P addresses the structural model.

The technical assessment of the finite element modeling architecture is provided in Section 2 of Reference 7. The general modeling architecture of this methodology (the use of one-dimensional dynamic models and a 3D structural model) is acceptable because it represents common analytical practice that is currently used in the industry, and the architecture follows all applicable regulatory guidance, such as RG 1.61 and RG 1.92. Further discussion on RG 1.92 is provided in Section 3.6.

The technical assessment of the CASAC finite element code is provided in Section 2.3 of Reference 7. In addition to reviewing the CASAC model description in Appendix A of ANP-10337P, the example problems documented in the CASAC 5.4.2 quality assurance report were audited. Independent calculations using ANSYS 17.2 were performed to recreate a number of the fundamental finite element sample problems. Based upon this material, CASAC 5.4.1 and CASAC 5.4.2 are acceptable for use with this methodology for dynamic and structural models.

3.4 Vertical Dynamic Finite Element Model

The vertical dynamic finite element model is comprised of springs, masses, and dampers, with finite element model parameters defined from mechanical testing. It represents a single fuel assembly. Section 5.3 of ANP-10337P describes the model architecture and application methodology and Section 6.2 of ANP-10337P described the required model input parameters and associated mechanical testing.

Figure 5-7 of ANP-10337P provides an illustration of the vertical fuel assembly model. In response to an RAI regarding the model parameters (RAI 4, Reference 2), Framatome updated this schematic identifying various parameters.

Section 5.3.1.1 of ANP-10337P states: "The transient hydrodynamic forces are the primary driver of the fuel assembly response. In cases where the core plate motions are shown to be negligible, this modeling of the core plates can be simplified to a rigid, stationary plate." The NRC staff had concerns with the lack of detail regarding this aspect of the vertical model. In response to an RAI regarding this provision (RAI 10, Reference 2), Framatome acknowledged that this aspect required more development and proposed its deletion from the TR. Change pages reflecting the removal of this provision are provided in Reference 2. Note that the last sentence of Section 7.3 has the same provision and also needs to be deleted in the final approval version ("-A") of ANP-10337P.

The technical assessment of the vertical dynamic finite element model is provided in Section 3 of Reference 7. The vertical finite element architecture is acceptable because it is a typical representation of a fuel assembly, formulated from mechanical test data, and it is consistent with all applicable regulatory guidance. It is upgraded from BAW-10133 to have more degrees of freedom to more accurately simulate fuel assembly dynamic behavior. Framatome is expected to apply engineering judgment when applying this methodology to identify and disposition non-physical vertical behavior in the model that can result from designing Framatome fuel based on non-Framatome core plate motion. If this methodology calculates non-physical results, it is up to Framatome to identify the problem and either demonstrate that the non-physical results are conservative or propose alternate methods to perform the analysis.

The technical assessment of the testing requirements is provided in Section 3.1 of Reference 7. In general, the testing is acceptable because it provided the information needed for the model and matched standard industry practice.

3.5 Horizontal Dynamic Finite Element Model

The horizontal dynamic finite element model is comprised of beams and rotational springs, which define the fuel bundle stiffness behavior, and classic springs and viscous dampers, which define the impact behavior. Section 5.2 of ANP-10337P describes the model architecture and application methodology and Section 6.1 of ANP-10337P described the required model input parameters and associated mechanical testing.

The term amplitude is used in many instances throughout Section 6 of ANP-10337P and the NRC staff had concerns with a consistent definition, especially when interpreting free and forced vibration test data. In response to an RAI regarding the definition of amplitude (RAI 6, Reference 2), Framatome provided further clarification which the NRC staff found acceptable.

The technical assessment of the horizontal dynamic finite element model is provided in Section 4 of Reference 7. There was a concern that the spacer grid impact model's inability to track permanent deformation of the grids prior to buckling was a problem that could lead to unrealistic and non-conservative results. In response to an RAI on this subject

(RAI 2, Reference 2), Framatome provided a sensitivity study that considers variations in grid-grid and grid-baffle gap sizes up to **[ ]**. Framatome's response to the RAI was found acceptable because it demonstrates a relatively small amount of analytical uncertainty related to permanently increased gaps by up to **[ ]**. The **[ ]**. This led to L&C #9.

L&C #9: **[ ]**

Section 5.2.2.3 of ANP-10337P describes hydrodynamic coupling. When an external loading (seismic or LOCA) is applied to a fuel assembly model, the hydrodynamic coupling element is used to account for: i) the added kinetic energy contained in the fluid when the fuel assembly moves in the lateral direction and ii) the lateral buoyancy force resulting from the lateral acceleration of the reactor internals. In response to an RAI regarding hydrodynamic coupling (RAI 3, Reference 2), Framatome stated that no changes were made relative to the previously approved methods in BAW-10133P-AA, Addendum 1. The RAI response also provided further clarification on the hydrodynamic coupling models and inputs.

The use of the **[ ]** to represent the fuel assembly bundle in the horizontal dynamic finite element model was questioned. Audit discussions explained that the **[ ]**. In response to an RAI regarding the **[ ]** This is acceptable because the acceptance criteria are tight enough that the potential for error related to mistuning the model is minimal. The horizontal model itself is a linear approximation of a nonlinear system, and the acceptance criteria require the linear approximation to behave as it is intended, within a reasonably small tolerance.

The horizontal dynamic finite element model is acceptable because it either matches typical vendor model architecture or has the same distinct features that were approved in BAW-10133P-A, but additional limitations are necessary regarding the implementation of the model within the ANP-10337P methodology. L&C's #1, #2, and #9 limit grid impact behavior and deformation that is simulated in the horizontal dynamic finite element model. L&C #3 is a limitation on the software used to implement the horizontal dynamic finite element model. L&C #4 limits the methodology to applications that are similar to the current operating fleet of PWR reactor and fuel designs. L&C #5 relates to the generic damping values used in the horizontal dynamic finite element model. There are nine L&C's placed on ANP-10337. The horizontal dynamic finite element model is approved for use within the bounds of all nine L&C's.

With respect to fuel bundle stiffness, the linear fuel bundle stiffness model described in ANP-10337P is acceptable for analyzing the current fleet of fuel and reactor designs. Outside the bounds of the current fleet, the large deflection range behavior is a problem for this methodology because the large deflection behavior of the model is not validated, and the methodology does not propose to collect data needed to demonstrate validation in the large deflection range.

With respect to the free vibration (pluck) test, the test defined in ANP-10337P is appropriate for the methodology because it is consistent with BAW-10133P-A, ANP-10337P defines an appropriate range of pluck amplitudes for the methodology, and the methodology is limited to the small deflection range by L&C #4.

Section 6.1.1.2 of ANP-10337P states: "Forced vibration tests can be used in lieu of free vibration tests for fuel assembly dynamic characterization for overlapping ranges of amplitudes." There was the concern about the possibility of replacing the pluck test with a forced vibration test because forced vibration tests typically have too small of a range of motion to define the full range of relevant fuel assembly dynamic behavior. In response to an RAI on this subject (RAI 8, Reference 2), Framatome stated that if new equipment becomes available they may replace free vibration tests with forced vibration tests. In theory, such a switch is reasonable and could successfully create a reasonable dynamic finite element model, but the test protocol is not defined in ANP-10337P and Reference 7 has no basis to approve a hypothetical forced vibration test designed to replace the pluck test. Given this lack of technical bases to approve this substitution, the NRC staff rejects the proposed alternative. If such a replacement test is proposed in the future, it is recommended that a direct comparison between a pluck test generated model and a forced vibration test generated model be made over the full deflection range of interest.

With respect to the forced vibration test, the test protocol is acceptable because it represents standard industry practice and is consistent with BAW-10133P-A.

With respect to the lateral stiffness test, the test is acceptable because it represents standard industry practice for informing structural models.

With respect to the dynamic grid crush test, there was a concern about the linear regression used to define the **[ ]** from test data. In response to an RAI requesting that Framatome define an R^2 limit on the grid impact test data (F2/MV2) to ensure that the data was sufficiently linear, and did not include bilinear or other nonlinear behavior (RAI 16, Reference 2), Framatome proposed a **[ ]**. This limit is acceptable because typical examples of grid data meet this limit and the amount of uncertainty it allows is comparable to the 95-percent lower confidence limit of true mean grid strength established in SRP 4.2. The grid test protocol is acceptable because it represents standard industry practice and is consistent with BAW-10133P-A. This contributed to L&C #1a below.

L&C 1a: **[ ]**

With respect to the dynamic impact test, the test protocol is acceptable because it represents standard industry practice and is consistent with BAW-10133P-A.

3.5.1 PNNL Modelling and Confirmatory Calculations

As described in Section 4.5 of Reference 7, PNNL replicated the Framatome horizontal dynamic finite element model in LS-DYNA, a commercially available general purpose explicit finite element code. The same basic finite element structure was used. The LS-DYNA model is not a perfect match of the CASAC model, but it is expected to be close enough to provide a sanity check on the CASAC model and provide a reasonable basis for certain sensitivity studies.

Section 4.5.1 of Reference 7 describes the analytical effort to match the results of the final sample problem. The first sample problem documented in ANP-10337P had a very benign horizontal loading environment. In response to an RAI requesting a more limiting sample problem (RAI 9, Reference 2), Framatome increased the magnitude of the core plate motion by a factor of three, and reduced the margins on the guide tube stresses and grid impact forces. Confirmatory calculations were performed on a subset of the more bounding analysis (15 fuel assembly row). As a review task, the purpose of the analysis was a sanity check, not a full recreation of Framatome's analysis. The sanity check was successful enough that a full modeling and analysis study was not warranted. The linear model of ANP-10337P is reasonably accurate and is acceptable.

Section 4.5.2 of Reference 7 describes a sensitivity study that implemented nonlinear stiffness in the LS-DYNA model by replacing the constant rotational spring stiffness of the ANP-10337P dynamic horizontal model with a piecewise linear relationship. The purpose of the study was to evaluate the response to RAI 7 (Reference 2) and test the assertion that the linear fuel bundle stiffness offered a more conservative model than a nonlinear bundle stiffness model. The conclusion from the study is that a nonlinear stiffness model can calculate a more limiting response for the same excitation scenario as a linear stiffness model. The linear and nonlinear stiffness models were evaluated at five different core plate excitation magnitudes (1x, 2x, 3x, 4x, and 5x, with 3x being the final core plate excitation for the sample problem in ANP-10337P, and 1x being approximately the original sample problem magnitude). The results demonstrate that the linear model is not always conservative in impact force or component stress, and supports the definition of L&C #4 to restrict the use of this methodology to the range of the current operating fleet.

3.5.2 Fuel Assembly Horizontal Damping

As described in Appendix C of ANP-10337P, there are three general sources of energy dissipation associated with the lateral motion of a fuel assembly:

- Structural damping is caused by the internal friction at the fuel rod spacer grid interface. The damping coefficient is a function of grid cells spring load which, in turn, is a function of bundle condition, i.e., irradiated versus non-irradiated.

- Viscous water damping is caused by the irrecoverable pressure losses that occur as the fuel rod lattice moves through water and the water is forced to accelerate and decelerate through the bundle. The main determining factors are the coolant properties, vibration amplitude, and lattice design.

- Axial coolant flow damping is caused by the hydrofoil effect associated with the axial flow rate and the lateral motion of the fuel assembly. The main factors are the coolant properties and axial flow rate.

Appendix C of ANP-10337P defines fixed fuel assembly damping ratios to be used in the horizontal dynamic models. The damping values represent the effective total of damping phenomena in the core under operating conditions. Fuel assembly damping is often measured in air, in still water, or in a flow loop, simulating flowing coolant conditions. Larger damping values generally relate to lower impact forces and component stresses because damping represents energy dissipation.

The technical assessment of the fuel assembly horizontal damping ratios is provided in Section 4.4 of Reference 7. Instead of testing fuel assembly damping on a case-by-case basis, BAW-10133P-A proposed generic damping values that were generally applicable to all fuel assembly designs. ANP-10337P is proposing the same generic damping values for BOL conditions. Specifically, critical damping ratios of **[ ]** for first and third mode damping, based on additional flow loop testing in Addendum 2 to BAW-10133P-A (October 2000). This is acceptable because it matches what was previously approved by NRC, the prior empirical database remains valid, and the additional damping test data provided in Appendix C supports the previously approved BOL damping values.

The new material in ANP-10337P related to horizontal fuel assembly damping is the definition of EOL damping values. Test data to support the EOL damping values was provided in C.3 of ANP-10337P. The EOL technical basis for damping is similar to the BOL technical basis for damping, with the EOL tests performed under simulated irradiated conditions. The simulated irradiated test data supports much higher damping values than the **[ ]** proposed in this methodology. The **[ ]** is well supported by the test data, but not to the same level of conservatism as the first mode data. The EOL damping values are acceptable because data was presented that supports their use, and the same kind of demonstration was made for previously approved BOL damping values.

There was a concern that changes in geometry, materials, and other aspects of PWR fuel design could challenge the generic applicability of the fixed damping ratios. The following L&C is intended to address this concern.

> **L&C #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.

Section 6.1.3.3 of ANP-10337P describes the process for adjusting critical damping factors based on a loss of forced flow scenario. The amount of detail describing the **[ ]** was concerning. At the May 2017 audit, the review team reviewed internal Framatome technical reports that partially explained how **[ ]** would be performed. In response to an RAI on this subject (RAI 13, Reference 2), Framatome provided further detail. The **[ ]** are appropriate because conservative assumptions are made to **[ ]** the damping as it decreases with decreasing flow rate.

3.5.3 Mixed Core Evaluation

The horizontal assembly row model (Section 5.2.2 of ANP-10337P) introduces the topic of mixed core configurations.

> Heterogeneous core models can be created to account for mixed core conditions. In this case, more than one type of single fuel assembly model is used to build row models in which dissimilar fuel assembly designs are adjacent to each other. Mixed core studies can be performed using the actual row configurations for a specific core design, or in cases where the core design is not available, the mixed core study can be performed generically by evaluating multiple row model permutations that reasonably encompass the fuel assembly response.

In response to an RAI regarding mixed core evaluations (RAI 1, Reference 2), Framatome provided further information on how non-Framatome fuel assemblies would be addressed. Framatome's response indicated that the finite element model of Framatome fuel assemblies would always be done according to the standard modeling described in ANP-10337P. However, the information needed to build the standard models for other vendor's fuel is generally not available. To accommodate this, ANP-10337P includes the flexibility to model other vendor's fuel assemblies the same way they are modeled by the other vendors. This includes changes to the damping formulation and the fuel bundle finite element model structure. One limitation inherent to the methodology (as discussed in ANP-10337P Section 6.1.5) is that co-resident fuel is only treated as a boundary condition for the Framatome fuel assemblies evaluated according to this methodology. Co-resident fuel is not evaluated against acceptance criteria.

The technical assessment is provided in Section 4 of Reference 7. The treatment of co-resident fuel in ANP-10337P is acceptable because the model replicates the design basis representation of the co-resident fuel to provide reasonable boundary conditions to the fuel of interest.

For future applications involving fuel transitions, the NRC should pay close attention to the mixed core evaluation performed by each fuel vendor.

3.6 Nonlinear Structural Finite Element Model

The nonlinear structural FEA model is used to calculate non-grid component stresses based on the loads calculated in the vertical and horizontal dynamic finite element models. The technical assessment of the nonlinear structural FEA model is provided in Section 5 of Reference 7. The nonlinear structural FEA model is acceptable because it represents established practice for applying correct boundary conditions and loading on the various components of the fuel assembly.

Section 8.1 of ANP-10337P states that ANSYS or "another finite element analysis software package" could be used in place of CASAC. During audit discussions, Framatome explained its intent was to use CASAC 5.4.2 and CASAC 5.4.1, but wanted flexibility to apply the methodology with any finite element software. The vertical and horizontal dynamic finite element models contain capabilities that are not always available in general finite element codes, and could require the use of user-defined subroutines or other advanced modeling features to recreate the dynamic finite element models in other codes. The structural modeling uses more standard finite element modeling features, but the methodology does not prescribe all the features and composition of the structural models in the same level of detail as it prescribes the dynamic models. The NRC staff accepts that finite element codes other than CASAC 5.4.2 and CASAC 5.4.1 can be used with this methodology, provided they are verified against sample problems and verified against CASAC 5.4.2 or CASAC 5.4.1 results. L&C #3 defines limitations associated with implementing the methodology of ANP-10337P outside of CASAC 5.4.1 and CASAC 5.4.2. See Section 2.4 of Reference 7 for further information.

L&C #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.

ANP-10337P does not define a methodology for fuel rod structural evaluations. L&C #6 is defined to require fuel rod evaluation with every application of this methodology. It is expected that the fuel rod evaluation will be reviewed at NRC's discretion.

L&C #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 way Framatome intended to determine the limiting deflection shapes calculated from the dynamic finite element models for application to the 3D structural model was of concern. In response to an RAI on this subject (RAI 18, Reference 2), Framatome described the stress indicators that are used (**[ ]**) and identifies options for time phasing or not time phasing the loads. The option that does not involve time phasing is acceptable because it follows RG 1.92.

The option that uses time phasing to construct limiting deflection shapes is potentially problematic because it does not follow the rigorous method defined in RG 1.92 for time phasing seismic structural analyses. Framatome's time phasing strategy is acceptable based on L&C #4, which limits the application of this methodology to the current fleet, where operational experience is valid, and Framatome's assumptions of the most limiting deflection shapes are credible.

In cases where time phasing is not used, Framatome intends to take the limiting X and Z horizontal deflection shapes throughout the core, and throughout time, and apply them to the structural model to calculate component stresses that are expected to be conservative. This approach is simple, but it potentially over predicts stress because peak X and Z stresses do not necessarily occur at the same time, or on the same fuel assembly in the core. A limitation is needed in this case because the acceptance criteria are different for fuel assemblies in control rod locations and those that are not in control rod locations. L&C #7 requires non-time phased loads to be applied to control rod locations, which have more limiting stress criteria than the non-control rod locations.

L&C #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.

There was a concern that ANP-10337P includes the option of evaluating **[**
]. This issue was discussed during the May 2017 audit. RG 1.92 provides guidance for combining responses in 3 orthogonal dimensions.
[

]

> **L&C #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 structural modeling defined in ANP-10337P is acceptable with the L&Cs described above.

Based upon the above discussion, the NRC staff finds the horizontal and vertical dynamic finite element models and nonlinear structural finite element model acceptable.

4.0 CONCLUSION

Based upon its review of TR ANP-10337P and RAI responses, regulatory audits, and technical support provided by PNNL, the NRC staff finds Framatomes's generic methodology to evaluate the structural response of PWR fuel assembly designs subjected to dynamic loads under seismic and LOCA events acceptable. Licensees referencing this TR will need to comply with the limitations and conditions listed in Section 5.0.

5.0 LIMITATIONS AND CONDITIONS

Licensees referencing the ANP-10337P TR must ensure compliance with the following limitations and conditions:

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. **[**
   ]

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, [ ]

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.

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.

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.

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.

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.

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). **[** **]**.

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

6.0 REFERENCES

1. AREVA Letter NRC:15:035, "Request for Review and Approval of ANP-10337P, "PWR Fuel Assembly Structural Response to Externally Applied Dynamic Excitations," August 31, 2015 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML15266A250).

2. AREVA Letter NRC:17:043, "Response to Request for Additional Information Regarding ANP-10337P, 'PWR Fuel Assembly Structural Response to Externally Applied Dynamic Excitations'," October 20, 2017 (ADAMS Accession No. ML17297A468).

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5. NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants" (SRP), Section 4.2, "Fuel System Design," Revision 3, March 2007 (ADAMS Accession No. ML070740002).

6. BAW-10133-P(A), Addendum 1 and Addendum 2 to BAW-10133P-A-A, Revision1: Mark-C Fuel Assembly: LOCA-Seismic Analyses, Addendum 1, 2000.

7. PNNL Technical Evaluation Report, "Technical Evaluation Report of ANP-10337P," February 2018 (ADAMS Accession No. ML18059A762, Not Publicly Available).

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