# Enclosure 3

Summary of proprietary markings and minor clarifications for Draft SE of ANP-10344P, Revision 0, “Framatome Best-Estimate Enhanced Option III Methodology”

| Change Number | Page Number | Line Number/s | Comment |
|---|---|---|---|
| 1. | 1 | 17 | Change Estimate to estimate |
| 2. | 3 | 121 | Change “channel DR” to “ICO FoM” |
| 3. | 3 | 142 | Remove extraneous “the” |
| 4. | 6 | 244 | Remove extraneous “Regulatory Requirements Summary.” |
| 5. | 9 | 379 | Change “channel MCPR” to “ICO FoM” |
| 6. | 10 | 443 | Clarify by changing to ICO FoM |
| 7. | 10 | 453 | Clarification language requested. Change “from the initial steady-state” |
| 8. | 11 | 484-485 | Remove extraneous text to **[[ ]]** |
| 9. | 11 | 502-503 | Language clarified to reflect stage 3 analysis, **[[ ]]** |
| 10. | 12 | 528 | Language clarified to reflect stage 3 analysis, :reduction instead of change |
| 11. | 12 | 532 | Change “ICO” to “channel” |
| 12. | 12 | 539 | Change “ICO” to “channel” |
| 13. | 12 | 568 | Change “MCPR responses” to “FoMs” |
| 14. | 13 | 579 | Corrected typo |
| 15. | 18 | 834 | Clarification language requested to allow other means |
| 16. | 19 | 872 | Corrected typo “the” instead of “these” |
| 17. | 22 | 1012 | Correction typo to generic BEO-III methodology |
| 18. | 25 | 1157-1162 | Clarification language requested to allow either AURORA-B or COTRANSA2 |
| 19. | 25 | 1171-1173 | Remove extraneous text to **[[ ]]** |
| 20. | 27 | 1237-1238 | Change “MCPR response” to “FoM” |
| 21. | 27 | 1241 | Change “MCPR” to “FoM” |
| 22. | 30 | 1399 | Clarified language “across all exposures” |
| 23. | 32 | 1476 | Corrected typo 8 not 9 |
| 24. | 33 | 1557-1559 | Framatome interprets this to mean that reduced initial flow and artificial destabilization can be used to establish an oscillatory final statepoint that demonstrates the 95/95 period remains above Tmin. |
| 25. | 35 | 1654-1655 | Additional reference to COTRANSA2 approved methodology to address item 18. |
| 26. | Throughout | - | Information that should be marked as Proprietary is highlighted in Yellow. |

# DRAFT SAFETY EVALUATION FOR FRAMATOME INC.

## TOPICAL REPORT ANP-10344P, REVISION 0

## "FRAMATOME BEST-ESTIMATE ENHANCED OPTION III METHODOLOGY"

## EPID L-2019-TOP-0046

## PROJECT NO. 728

## DOCKET NO. 99902041

## 1.0 INTRODUCTION

Framatome Inc. (Framatome) submitted Topical Report (TR) ANP-10344P, "Framatome Best-e~~E~~stimate Enhanced Option III [(BEO-III)] Methodology," to the U. S. Nuclear Regulatory Commission (NRC) on October 31, 2019 (Ref. 1). This TR is intended to support analysis of stability for boiling water reactors (BWRs).

Following stability events that occurred at BWRs during the late 1980s (Ref. 2) and early 1990s (Ref. 3), in response to NRC staff concerns, the industry made a number of improvements to analytical methods, plant hardware, and plant operations. Among these improvements were algorithms and associated analytical methods intended to allow detection and suppression of oscillatory behavior, while avoiding unnecessary reactor trips. The BEO-III methodology described in ANP-10344P builds upon these industry efforts and the subsequent evolution of Framatome's methods for analyzing stability.

In particular, Framatome's BEO-III methodology is similar to a plant-specific BEO-III approach that the NRC staff has previously reviewed in a plant-specific license amendment to support a transition to ATRIUM 11 fuel at the Brunswick Steam Electric Plant (Brunswick). This plant-specific methodology is documented in TR ANP-3703P, "BEO-III Analysis Methodology for Brunswick Using RAMONA5-FA" (Ref. 4). The NRC staff found the plant-specific methodology for Brunswick to be acceptable as documented in Section 3.6, "Stability Analysis Using Plant-Specific Best-Estimate Option III (BEO-III) Approach," of its safety evaluation (SE) dated March 6, 2020 (Ref. 5).

The description of the generic BEO-III stability methodology summarized in this SE is based primarily upon Framatome's TR ANP-10344P, and a supporting response to a request for additional information (RAI) dated November 30, 2020 (Ref. 6).

## 2.0 REGULATORY EVALUATION

The generic BEO-III methodology was developed to support a demonstration of BWR licensees' compliance with requirements governing stability in General Design Criteria (GDC) 10 and 12 in Title 10 of the *Code of Federal Regulations* (CFR) Part 50, Appendix A, "General Design Criteria for Nuclear Power Plants."

Criterion 10, "Reactor design," requires that "The reactor core and associated coolant, control, and protection systems shall be designed with appropriate margin to assure that specified acceptable fuel design limits are not exceeded during any condition of normal operation, including the effects of anticipated occurrences."

Criterion 12, "Suppression of reactor power oscillations," requires that "The reactor core and associated coolant, control, and protection systems shall be designed to assure that power oscillations that can result in conditions exceeding specified acceptable fuel design limits are not possible or can be reliably and readily detected and suppressed."

## 3.0 TECHNICAL EVALUATION

### 3.1 Overview and Relationship to Previous Stability Methodologies

The applicant's proposed generic BEO-III methodology makes use of Framatome's RAMONA5-FA code (Ref. 7), which has been previously approved for stability calculations as part of the Option III (Ref. 8) and Enhanced Option-III (EO-III) methodologies (Ref. 9). The Option III methodology determines the delta-critical power ratio (CPR) response during anticipated oscillations by performing an analysis consisting of three primary components:

- The first component consists of determining the minimum critical power ratio (MCPR) margin that exists prior to the onset of oscillations. This is a plant- and cycle-specific determination that is based on the plant response to a two recirculation pump trip (2RPT), as well as during steady-state operation at reduced flow conditions.

- The second component of the calculation determines to a 95/95 statistical tolerance limit the largest oscillation amplitude expected prior to oscillation suppression for a given plant configuration using analytically prescribed oscillation power range monitor (OPRM) response signals with assumed statistical distributions for oscillation growth rate, oscillation mode, and other relevant parameters.

- The third component of the calculation uses the Delta over Initial Versus Oscillation Magnitude (DIVOM) correlation to conservatively compute the delta-CPR response associated with this 95 percent probability with 95 percent confidence (95/95) oscillation amplitude. The DIVOM correlation is developed based on the MCPR response calculated by RAMONA5-FA during simulated oscillations of growing amplitude, starting from assumed conditions representative of the plant following a two recirculation pump trip.

This approach of dividing the calculation process into three separate components introduces significant conservatism into the calculation of operating limit MCPR (OLMCPR) values. For example, because the statistical analysis component does not use best-estimate RAMONA5-FA calculations to determine the core response during growing oscillations, the assumption is made that the oscillations grow with a constant decay ratio (DR) from the time of oscillation inception until suppression. Depending on statistical sampling, the constant DR value can be well above 1.0. However, assuming a DR value significantly above 1.0 from the time of oscillation inception is conservative. In a realistic recirculation pump trip (RPT) event, the oscillation growth rate will begin at 1.0 at oscillation inception and gradually increase over time. This is due to the gradually decreasing core inlet temperature throughout the event, as well as changes in the recirculation pump driving flow that may continue into the early portion of the oscillations. These initially slower-growing oscillations increase the likelihood that sufficient successive oscillation counts will be recorded by the period-based detection algorithm (PBDA) prior to the oscillations exceeding the amplitude setpoint. Accordingly, the Option III and EO-III assumption of using a fixed oscillation DR leads to a conservatively high hot channel oscillation amplitude. Another conservatism lies in the process of calculating the DIVOM slope, which determines the MCPR response of fuel assemblies in the core under oscillatory conditions in a bounding (rather than best-estimate) manner.

The EO-III methodology employs the same process as Option III for determining the core MCPR response during anticipated oscillations. However, EO-III also calculates the limiting growth or DR for individual channel oscillations (ICOs) in the core. **[[**

**]]** The existence of ICOs simultaneously with whole-core oscillations invalidates the assumptions of the DIVOM relationship and is unsuitable under these conditions. Therefore, in conjunction with the normal DIVOM approach, EO-III implements a scram region, known as the channel instability exclusion region, to ensure that the power will be suppressed before ICOs may develop.

BEO-III discards the three-step approach used in Option III and EO-III. Instead, BEO-III performs cycle-specific best-estimate RAMONA5-FA evaluations in which the entire event, including the initiating pump trip and subsequent growth of oscillations, is explicitly modeled. The event MCPR response and ~~channel DR~~ICO FoM are then determined to a 95/95 tolerance limit to ensure adequate safety limit MCPR (SLMCPR) protection. These 95/95 values are determined by performing a set of statistical trials in which physical modeling parameters are randomly varied according to appropriate uncertainty distributions.

By explicitly modeling the plant and core response to the potentially limiting RPT events, explicitly treating uncertainties through a statistical process, and directly calculating the MCPR response from the oscillations that develop, many of the conservatisms inherent in the three-step approach of Option III and EO-III are avoided. Best-estimate assumptions are made for most of the modeling aspects of BEO-III; however, in some specific areas, Framatome made conservative assumptions to ensure that the BEO-III predictions remain bounding with respect to the safety criteria.

Many of the underlying modeling aspects of the BEO-III methodology remain the same relative to Option III and EO-III. However, this is the first NRC review of a generic methodology in which RAMONA5-FA is used within a statistical framework to determine the MCPR response and associated uncertainty during stability events. Therefore, the NRC staff focused its review on determining the acceptability of the new modeling features that were added to RAMONA5-FA, as well as the acceptability of the statistical approach to ensure that the safety limits are met during any anticipated oscillations in operating BWRs.

A plant-specific BEO-III methodology for ~~the~~ Brunswick described in ANP-3703P (Ref. 4) was previously reviewed by the NRC staff and approved for Brunswick over an operating domain that includes Maximum Extended Load Limit Line Analysis Plus (MELLLA+) (Ref. 5). The Brunswick plant-specific BEO-III methodology is similar or identical to the generic BEO-III methodology in ANP-10344P in many respects. The main difference between the two methods is that for Brunswick, a separate post-processing step was necessary to simulate the behavior of the proprietary stability algorithm of a different fuel vendor. The generic version of the BEO-III methodology in ANP-10344P is based on the PBDA, and the additional post-processing step used in the Brunswick application is not necessary. Consequently, the NRC staff's review of the generic BEO-III methodology in ANP-10344P builds upon the previous review of the Brunswick plant-specific BEO-III methodology, focusing especially on areas where differing approaches were employed.

### 3.2 Regulatory Requirements Summary

As discussed in Section 2.0 of this SE, GDC 10 and 12 of Appendix A to 10 CFR Part 50 require that specified acceptable fuel design limits (SAFDLs) not be exceeded under normal operation or anticipated operational occurrences (AOOs). The relevant SAFDL for stability events is the SLMCPR.

The applicant identified two figures of merit (FoMs) that were used to demonstrate compliance with GDC 10 and 12:

- Core MCPR at the time of oscillation suppression, referred to hereafter as the “core MCPR FoM”

- Verification that ICOs do not invalidate the assumption that the reactor protection system can detect and suppress the oscillations prior to violation of the SAFDLs, referred to hereafter as the “ICO FoM”

Framatome evaluated the core MCPR based on simulated oscillation suppression times using the PBDA. The specific manner in which the core MCPR and ICO FoMs were assessed in the context of the statistical analysis is provided in Section 7.0, “BEO-III Cycle-Specific Analyses,” of ANP-10344P, as evaluated below in Section 3.7, “BEO-III Cycle-Specific Analyses.”

### 3.3 Scenario Identification

The applicant identified a 2RPT from the minimum flow condition at rated power within the extended flow window (EFW)[1] operating domain to be the limiting event for the stability analysis. This limiting event identification is consistent with previous plant-specific applications of Option III and EO-III. Pump trip events may lead to instability due to a large reduction in core flow rate combined with a relatively modest reduction in power, which moves the core toward the upper left (low-flow, high-power) corner of the power-flow operating map. These conditions promote unstable oscillations.

In particular, the 2RPT event from the lowest flow at rated power is expected to be the most limiting pump trip event because it starts from operation at the highest control rod line, which results in the highest power level, and therefore, the most unstable condition following the RPT.

However, there exists a possibility that other events may be limiting, depending on the specific conditions at the plant. The proposed methodology also analyzes a 2RPT from the lowest-flow point at rated core power within the MELLLA domain with the minimum allowed feedwater (FW) temperature under FW heater out-of-service (FWHOOS) conditions. A lower FW temperature gives higher core inlet subcooling, which is destabilizing. Note that FWHOOS is not allowed during EFW operation. Therefore, this initial operating condition in the MELLLA domain may be

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[1] Note that the EFW terminology used by Framatome is comparable to the MELLLA+ terminology used by GE-Hitachi.

more limiting than the operating condition in the EFW domain due to the core inlet temperature difference.

The methodology also evaluates a 1RPT event starting from the highest power level under single-loop operation (SLO) conditions. This may be a limiting event because it results in flow at natural circulation conditions similar to the 2RPT event. **[[**

**]]**

As stated in Section 7.2, “BEO-III Calculation Procedure,” of ANP-10344P, the applicant proposes to evaluate all three of these pump trip scenarios **[[**

**]]** The NRC staff has high confidence that the limiting stability event will be one of these three events based on past experience and consistency with previous applications of Option III and EO-III. Therefore, the analysis of these three events in plant-specific applications is appropriate and sufficient. For scenarios which are non-limiting by a significant margin above normal cycle variation, the applicant also proposes to **[[**

**]]** The NRC staff’s evaluation of this proposal is given in Section 3.7.2, “BEO-III Calculation Procedure.”

## 3.4 Evaluation Model Requirements

RAMONA5-FA is currently approved for DIVOM analyses within the Option III and EO-III methodologies. These DIVOM analyses involve calculation of the system stability response starting from natural circulation conditions after the pump trip has completed. These analyses must be able to accurately calculate the MCPR response as a function of oscillation amplitude as the oscillations grow. However, the magnitude of oscillations that occur before they are suppressed by a trip, is determined separately from the RAMONA5-FA calculations in these previous methodologies.

The BEO-III methodology is used to determine **[[** **]]** the MCPR response during unstable oscillations, as in the Option III and EO-III methodologies. Therefore, the evaluation model requirements[2] related to the growth of oscillations and associated MCPR response are the same for BEO-III as in these previous methodologies.

However, unlike the Option III and EO-III methodologies, the BEO-III RAMONA5-FA analyses start from normal operating conditions and explicitly model the RPT and associated core inlet flow and temperature response. Therefore, accurate modeling of the time-dependent plant response following a RPT is required for BEO-III as well. Another difference is that BEO-III implements the PBDA algorithm directly into RAMONA5-FA in order to simulate the OPRM response and PBDA trip generation time for the time-dependent RAMONA5-FA 3D power distribution. This requires that the PBDA algorithm be properly implemented, in order to accurately determine trip times and resulting MCPR values for a given plant-specific application. The applicant developed a phenomena identification and ranking table (PIRT) to determine which model uncertainties are important in determining the core MCPR FoM and the ICO FoM as defined in Section 2.0, “Regulatory Requirements Summary,” of ANP-10344P (Ref. 1),

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[2] Note that the term “evaluation model requirements” is used in the sense specified in RG 1.203, which describes the evaluation model development and assessment process (i.e., EMDAP).

~~"Regulatory Requirements Summary."~~ This table summarizes all the relevant phenomena and provides an importance ranking with respect to each FoM. The NRC staff evaluated the BEO-III PIRT in detail due to its importance in determining the evaluation model requirements for BEO-III, as well as in defining the uncertainty parameters included in the statistical uncertainty analysis performed for BEO-III.

Based on its review of the BEO-III PIRT, the NRC staff finds that the applicant identified all significant parameters that are relevant to the FoMs and that appropriate importance rankings were assigned to each of them. The applicant considered not only phenomena that impact the neutronic and thermal-hydraulic dynamics of the core during oscillations, but also phenomena that impact the plant and vessel response following a RPT. The NRC staff determined these phenomena and their rankings to be consistent with the current state of understanding of BWR oscillations. In order to make this determination, the NRC staff reviewed PIRTs developed under the guidance of the NRC in 2001 (Ref. 10) and 2011 (Section 5 of Ref. 11), more recent NRC-published studies of ATWS-I scenarios (Ref. 12) and (Ref. 13), and other available sources of information from open literature or internal NRC experience based on reviewing ATWS-I methodologies.

The NRC staff also compared the BEO-III PIRT to the ATWS-I PIRT presented in ANP-10346P (Ref. 14). Although the FoMs are not identical, the NRC staff expected that many of the same phenomena would be identified in both PIRTs due to the similarity of the two applications. This was found to be the case, as all relevant phenomena in the ATWS-I PIRT were considered in the BEO-III PIRT as well. Furthermore, the importance of these phenomena was indicated as the same or higher in BEO-III relative to ATWS-I, which is consistent with the NRC staff's expectations.

Additional Potentially Significant Phenomena

The NRC staff further identified two phenomena that were dispositioned as being of low importance in the BEO-III PIRT, but which the NRC staff considered to have a potentially significant impact for stability. Additionally, in some cases, these parameters were included in the AURORA-B AOO statistical sampling for non-pressurization transients, which uses similar methods as BEO-III. These phenomena are:

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

**[[**

**]]** The NRC staff finds that this assumption is conservative **[[**

**]]** Therefore, the NRC staff finds this treatment of **[[**
**]]** to be acceptable and finds that no ~~[[~~statistical sampling~~]]~~ of this parameter is needed.

**[[**

]]

The NRC staff issued RAI-2 to obtain additional justification for [[ ]] as low importance, considering its physical relevance to stability dynamics. In particular, this [[ ]] may have a stronger impact on global oscillations than on regional oscillations. This is because the total flow rate outside the core remains nearly constant for regional oscillations but not for global oscillations. Therefore, plant or cycle applications which are global- or mixed-mode-limited could exhibit a greater sensitivity to these parameters than regional-limited applications such as the MELLLA+ sample problem.

In the RAI response, Framatome analyzed the behavior for [[ ]] As noted above, the impact on regional oscillations is expected to be even less. Therefore, the NRC staff finds that the disposition of [[ ]] as low importance, and its exclusion from statistical sampling is acceptable.

Because of its consistency with the NRC staff's understanding of BWR stability and the similarity to previous stability PIRTs, the NRC staff finds the BEO-III PIRT presented in ANP-10344P to be acceptable for generic application.

<u>Core Flow and Power Uncertainty</u>

The total core flow rate and total core power were dispositioned as being of high importance in the BEO-III PIRT. The NRC staff issued RAI-7 to obtain additional justification for their exclusion from statistical sampling.

In the RAI response, the applicant [[

]]

The NRC staff agrees that the standard BEO-III approach may often be conservative in practice; however, it is difficult to ensure conservatism for all plants and cycle designs, particularly if the limiting exposure points occur when the nominal flow rate is at or near the minimum allowed value.

The NRC staff examined additional results in RAI-7 for a case that assumed a minimum flow and maximum power, [[

**]]**

The SLO **[[**

**]]**

In its RAI response, the applicant also justified that operating flow and power uncertainties are accounted for when determining the SLMCPR. The NRC staff finds that the impact of power and flow uncertainties is partially, but not fully, accounted for via the SLMCPR calculation. In particular, the SLMCPR calculation does not fully account for these uncertainties' impact on the growth rate and magnitude of oscillations (and therefore the hydraulic conditions in the core at a given point in time) during the transient.

However, in Section 3.7.2 of this SE, the NRC staff concluded that the approach of **[[**

**]]**

Considering that **[[**

**]]**
and the significant conservatism inherent in the ~~channel MCPR~~ICO FoM calculation approach, the NRC staff concludes with high confidence that the BEO-III predictions will remain conservative overall, in the absence of flow and power uncertainty sampling, provided that the minimum flow rate and maximum power MELLLA+ point is used for all calculations. Therefore, the NRC staff finds the treatment of core flow and power uncertainties to be acceptable considering the overall balance of conservatisms in the generic BEO-III methodology.

### 3.5 Method Adaptations for BEO-III

The version of the RAMONA5-FA code used for BEO-III is identical to that used in the approved EO-III and Option III methodologies, with several exceptions that are discussed and evaluated in the following sections of this evaluation.

### 3.5.1 Fuel Rod Models

Fuel rod modeling impacts the thermal energy stored in the fuel rod and the heat that reaches the cladding surface and coolant during thermal-hydraulic oscillations. Therefore, the BEO-III model must adequately determine the initial condition of the fuel rod, the change in fuel rod conditions following the initiating event (e.g., 2RPT), and the change in fuel rod conditions during growing oscillations up until oscillations are suppressed by a scram.

For the BEO-III methodology, **[[** **]]** In the SE for ANP-10346P (Ref. 15), the NRC staff concluded that the **[[** **]]** fuel rod model acceptably simulates fuel behavior under the full range of conditions expected for ATWS-I.

Limiting ATWS-I events, such as 2RPT, are identical to stability events except that the ATWS-I events are not terminated by a reactor scram. Therefore, the ATWS-I methodology must determine the fuel rod behavior under the same conditions as for BEO-III, as well as under larger-amplitude oscillations in the absence of scram. Therefore, the same evaluation given in the SEs for ANP-10346P (Ref. 15) and the plant-specific license amendment for Brunswick (Ref. 5) can be used to justify the fuel rod model in the generic BEO-III methodology. Additionally, the experimental benchmarking performed for BEO-III indicated no observable bias that would indicate a deficiency in the fuel rod modeling. For these reasons, the NRC staff finds that the **[[** **]]** fuel rod model is acceptable in both RAMONA5-FA and STAIF.

### 3.5.2 Radial Power Deposition Distributions in Fuel Pellets

The radial distribution of power deposition in the fuel pellets affects the fuel temperature distribution and the rate of heat reaching the cladding and coolant as a function of time during stability events. **[[** **]]** Therefore, the NRC staff finds the radial power deposition distribution model, which was found to be acceptable for **[[** **]]** is acceptable for BEO-III as well.

### 3.5.3 Period-Based Detection Algorithm Model

Framatome implemented the PBDA included in the Boiling Water Reactor Owners Group (BWROG) Long-Term Stability Solutions Option III solution (Ref. 16) and (Ref. 17) within RAMONA5-FA to determine the time of scram during the simulated oscillations. The NRC staff reviewed Section 5.3, “Period-Based Detection Algorithm Model,” of the TR and concluded that the PBDA was implemented properly into RAMONA5-FA and provides appropriate PBDA trip times and corresponding MCPR values, provided that the PBDA settings employed in the calculations are consistent with those of the plant being analyzed. RAMONA5-FA calculates trip times based on the PBDA only; application of BEO-III to a plant with a detect and suppress (D&S) algorithm other than PBDA would therefore extend beyond the scope of the generic BEO-III method being approved in the present SE.

### 3.5.4 Multi-Stage Analysis

As in the Brunswick plant-specific methodology, the generic BEO-III methodology employs a “multi-stage analysis” approach to determine both the core MCPR and the ICO FoM for a given statistical case. Due to its importance, the multi-stage analysis was a focus of significant attention during the NRC staff’s review. Details and the staff’s evaluation of each stage of the multi-stage approach are provided below.

**[[** **]]**

The NRC staff evaluated **[[** **]]** to determine its ability to adequately determine **[[** **]]** as lt of core oscillations during the limiting stability events. The NRC staff determined that the limiting stability events were simulated in a realistic manner, accounting for all important physics. **[[** **]]** The NRC staff finds that these best-estimate calculations were performed in an acceptable manner and are suitable for use **[[** **]]**

**[[** **]]**

The NRC staff reviewed the **[[** **]]** and finds that it is an acceptable means of determining **[[**

**]]**

**[[** **]]** The NRC staff issued RAI-5 to obtain specific information on the criteria that will be used for this determination. In the RAI response, Framatome specified that the Stage 3 analysis **[[** **]]**

The NRC staff finds this approach to be acceptable because **[[** **]]**

In the RAI-5 response, the applicant also provided **[[** **]]**

The BEO-III methodology calculates **[[** **]]** Therefore, the NRC staff finds that this calculation approach provides an acceptable approximation of **[[** **]]**

Figure 5-1, **[[**

**]]** The example in Figure 5-1 provides added confidence that this is true, and therefore that the Stage 3 results are reliable and accurate.

In RAI-1, the NRC staff requested a plot of core pressure drop **[[**

**]]** Thus, the NRC staff finds that **[[**
**]]** is acceptable.

An evaluation of expected **[[** **]]** compared to the Stage 3 approach is given in Section 3.7.2 of this SE. In that section, the NRC staff found the Stage 3 approach of **[[** **]]** to provide a conservative calculation of **[[**
**]]**

Based on these evaluations, the NRC staff finds that the core and ICO ~~MCPR~~ FoMs ~~responses~~ are adequately determined by the multistage analysis process.

## 3.6 Code Validation and Model Uncertainties

Section 6.0, “Code Validation and Model Uncertainties,” of ANP-10344P describes the determination of neutronic and thermal-hydraulic modeling uncertainties applicable to the BEO-III statistical analysis, as well as the benchmarking of these models to measured data.

### 3.6.1 Model Uncertainties

Table 7-3, “Sampled Parameters for ~~BE0-111~~ BEO-III ATRIUM 11 Statistical Analyses,” of ANP-10344P lists the parameters that were statistically sampled in the BEO-III licensing analyses. In Table 7-2, “Disposition of High and Medium-Ranked Phenomena,” of ANP-10344P, the applicant provided a disposition of each high- and medium-ranked parameter including justification for the exclusion of certain medium-ranked parameters from the statistical sampling.

In its evaluation of the AURORA-B AOO evaluation model in ANP-10300P (Ref. 18), which uses a similar statistical approach as BEO-III, in response to an RAI from the NRC staff, Framatome also included medium-ranked parameters in the statistical sampling. This was because the combined effect of the medium-ranked parameters on the final 95/95 result was considered large enough to warrant their inclusion, even if the impact of individual medium-ranked parameters may be relatively small. Based on this precedent, the NRC staff considered both high- and medium-ranked parameters in its evaluation. For parameters which were included in the statistical sampling, the NRC staff evaluated whether the sampling approach appropriately accounted for uncertainties. For parameters which were excluded from the statistical sampling, the NRC staff evaluated whether their exclusion was justifiable by having no significant impact on the FoMs.

All phenomena with high importance to either the MCPR FoM or the ICO FoM (or both) were included in the statistical sampling. Of the remaining phenomena, eight were assigned medium importance for at least one FoM. Four of these were selected by the applicant for inclusion in the set of sampled parameters:

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

The applicant provided justification for excluding the remaining four medium-ranked phenomena:

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

Uncertainties of Sampled Parameters

Parameters listed under **[[** **]]** were assigned uncertainties based on **[[** **]]**. The modeling uncertainty of each parameter is determined based on comparison to measured data, **[[** **]]** Because of these considerations, the NRC staff finds that these parameter uncertainties **[[** **]]** are acceptable for use in BEO-III.

The approach for determining parameter uncertainties in the BEO-III methodology includes **[[** **]]** The NRC staff reviewed the new uncertainty methods and determined that they remain within the spirit of the approved methods in AURORA-B AOO. **[[** **]]** Therefore, the NRC staff finds the methods used to determine uncertainties for all sampled parameters to be acceptable.

**[[** **]]** uncertainties were derived based on experimental void fraction data from the FRIGG and KATHY facilities. The FRIGG experiments included legacy geometric designs, while the KATHY experiments included benchmarking of ATRIUM-10 and ATRIUM 10XM fuel bundles. The **[[** **]]** uncertainty was determined based on experimental pressure drop data from KATHY for ATRIUM-10, ATRIUM 10XM, and ATRIUM 11 fuel. The ATRIUM-10 and ATRIUM 10XM designs include part-length-fuel rods, mixing vane grids, and prototypic axial/radial power distributions, which are reasonably representative of the design features in ATRIUM 11.

A sufficient degree of thermal-hydraulic compatibility with previous fuel types is a requirement for introducing new fuel types. The NRC staff notes that bundle thermal-hydraulic parameters, including pressure drop and void fraction distributions, depend primarily on bulk quantities such as bundle hydraulic diameter and are relatively insensitive to mild variations in the configuration of flow paths within the bundle. Therefore, the NRC staff finds it acceptable **[[** **]]** Note that Section 4.0, “Limitations and Conditions,” of this SE provides the NRC staff’s position on potential application of BEO-III to new fuel types beyond ATRIUM 11.

**[[** **]]** The NRC staff finds this approach to be acceptable because **[[** **]]**

**[[** **]]** Realistic modeling of reactor noise is important for stability calculations because it strongly affects the onset time and initial magnitude of oscillations as the core becomes unstable. The model used to define this random noise, including the values of parameters used to define the noise amplitude, as well as its temporal characteristics, **[[** **]]** it is expected to provide a realistic representation of the actual noise in terms of the distribution of amplitude and frequency ranges within the noise signal. Additionally, the noise parameters to be used for BEO-III analyses are consistent with those used for the validation cases, which provides confidence that the BEO-III analyses will produce accurate results consistent with the good experimental agreement demonstrated in ANP-10344P.

However, the random nature of noise means that the results will differ depending on **[[** **]]** This may impact oscillation onset timing to some degree, but the most significant effect is the possibility of PBDA resets due to the chaotic effects of the applied noise. Such resets can significantly impact the PBDA trip time in each statistical trial, and therefore, impact the final 95/95 FoMs. This chaotic effect is not a shortcoming of the model but a realistic representation of actual PBDA behavior in the plant.

To ensure that the final MCPR determination accounts for this noise-induced variability, the applicant has **[[** **]]** Therefore, the NRC staff finds the inclusion of **[[** **]]** to be acceptable. The NRC staff has determined that **[[** **]]**

### Medium-Importance Phenomena Excluded from Sampling

The following medium-ranked parameters were omitted from the statistical sampling in the ANP-10344P methodology:

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

The exclusion of these phenomena is discussed in the following paragraphs.

**[[** **]]**

The NRC staff reviewed **[[** **]]** modeling approach and finds it acceptable that MICROBURN-B2 contains sufficient modeling fidelity to accurately predict **[[**

]] The NRC staff finds that this impact is small enough that this parameter may be excluded from the BEO-III [[ ]] without significant adverse impact on the final FoMs.

[[

]]

In Section 6.9, [[ ]] of ANP-10344P, the applicant applied [[

]] The NRC staff finds that [[

]]

In addition to the impact of bypass flow rate on the thermal-hydraulic stability of the core, the NRC staff considered the impact of bypass voiding and its effect on OPRM miscalibration. At low core flow rates, particularly those characteristic of pump trip events, the bypass exhibits an especially low-flow rate, which can lead to boiling in the upper portion of the bypass due to direct gamma heating and neutrons slowing down in the bypass. The resulting void formation in the bypass reduces the sensitivity of the local power range monitors, which leads to error in the measured local power level and resulting miscalibration of the OPRM signal.

In its review of the EO-III methodology (Ref. 19), the NRC staff concluded [[

]]

Because BEO-III relies on the same D&S algorithm as EO-III, based on relative OPRM amplitude signals, the same conclusion applies, and [[ ]] are necessary to account for OPRM miscalibration.

Note that average power range monitor (APRM) miscalibration due to bypass voiding does impact the channel stability exclusion region of EO-III, as discussed in the SE for ANP-10262PA (Ref. 19). However, BEO-III does not calculate an exclusion region on the power-flow map; instead, the impact of ICOs is evaluated within the multistage analysis supporting BEO-III implementation. This does not involve detection of ICOs using plant hardware, and therefore the miscalibration of APRMs and/or OPRMs due to bypass voiding is not relevant for this determination. [[ ]] Note also that the impact of core power and flow uncertainties was discussed in Section 3.4, “Evaluation Model Requirements,” and that [[ ]]

[[ ]] In Section 6.11, [[ ]] of ANP-10344P, the applicant indicated that [[ ]] Therefore, the NRC staff finds that [[ ]] can be acceptably excluded from the [[ ]]

The recirculation pump coastdown behavior affects the time required for the core flow rate to decrease to natural circulation conditions following a pump trip. If this time is sufficiently long, the elevated flow rates may delay the onset and early growth behavior of oscillations. This could cause a significant change in oscillation period from one oscillation to the next; if this change is large enough, the PBDA might not identify subsequent oscillations correctly, which may cause the PBDA successive oscillation counts to reset, resulting in a possible delay in the eventual PBDA trip signal timing.

[[ ]]

Because of this possibility, the NRC staff issued RAI-10 to obtain additional justification for the exclusion of the pump coastdown uncertainty from the statistical analysis. [[ ]]

The NRC staff finds this approach to be acceptable [[

]]

Table 1:  Modeling Parameters Included in the BEO-III Statistical Analysis

| Category | Parameter | PIRT Importance |
|---|---|---|
| [[ | | ]] |

### 3.6.2 Impact of Core Oscillation Mode

Certain system phenomena may impact which core oscillation mode occurs (global, regional, or mixed) and/or may have a stronger impact on the FoMs under one mode compared to the other. As part of its review, the NRC staff considered whether the appropriate phenomena were included in the statistical sampling to accurately predict the oscillation mode and the impact on the FoMs for all expected plant conditions.

~~[[~~Having higher bundle powers in the radial center of the core promotes in-phase oscillations, while having higher powers toward the periphery promotes out-of-phase oscillations due to the impact on the out-of-phase mode subcriticality. **[[**

**]]** The **[[** **]]** was evaluated in Section 3.4 of this SE and its exclusion from statistical sampling was found to be acceptable. The **[[** **]]** are included in the statistical sampling.

Based on these findings, the NRC staff has determined that the appropriate phenomena were included in the methodology to accurately predict the oscillation mode and resulting impact on the FoMs, under all anticipated operating conditions.

### 3.6.3 Additional Code Validation

The validation of RAMONA5-FA against KATHY void fraction and pressure drop data is discussed and evaluated in the previous section. Additional experimental benchmarking was performed against measured stability data. These include KATHY stability tests, KATHY dryout/rewet tests, linear reactor stability benchmarks, and a nonlinear reactor stability benchmark. The tests encompass a wide range of conditions that provide sufficient coverage of the expected core conditions during anticipated oscillations at BWRs.

These stability benchmarks were also performed for the generic RAMONA5-FA ATWS-I methodology described in ANP-10346PA (Ref. 15). The benchmarks include experimental validation for the onset of oscillations, growth of oscillations, occurrence of dryout, and post-dryout behavior. In its review of ANP-10346PA, the NRC staff concluded that the RAMONA5-FA ATWS-I code demonstrated close agreement with the measured data and that this benchmarking was sufficient to justify the use of the RAMONA5-FA ATWS-I code for ATWS-I applications.

The BEO-III methodology analyzes the same physical phenomena as the ATWS-I methodology, with the exception of not treating post-dryout behavior. The NRC staff reviewed the benchmarking results for the BEO-III version of RAMONA5-FA and determined that the agreement with measured data was comparable to what was observed for RAMONA5-FA ATWS-I and that the agreement remains acceptable. Statistical trials were also performed to determine upper 95/95 bounds for DRs, frequencies, and other results across these benchmarks when relevant statistical parameters were considered. The statistical perturbations led to a reasonable degree of variation in the calculated results, and in the majority of cases the 95/95 DR results bounded the experimental data, which is expected. Overall, RAMONA5-FA tended to predict **[[** **]]** However, as discussed in its review of ANP-10346PA, this apparent bias in **[[** **]]** did not lead to an unacceptable discrepancy in **[[** **]]**. The NRC staff finds that the applicant's BEO-III methodology, including treatment of uncertainties, is acceptable because its modeling result for the stability response and dryout occurrence during anticipated instability events is consistent with the measured data.

### 3.6.4 Timestep Size and Nodalization

Spatial and temporal discretization may impact the stability behavior predicted by system thermal-hydraulic codes such as RAMONA5-FA. It is often found that increasing the timestep size leads to increased oscillation DRs, regardless of oscillation mode due to reduction in numerical damping. Increasing the number of axial nodes in the core may have a similar effect by reducing the numerical damping, as well as increasing the spatial resolution. However, increasing the number of axial nodes in the vessel is only expected to have a significant effect on numerical damping for in-phase modes. This is because the total core flow rate, and therefore, the flow rate in the vessel nodes, is essentially constant during out-of-phase oscillations. In either case, vessel nodalization may also impact the core inlet subcooling by affecting the transport of fluid energy through the vessel as the FW temperature decreases during the event.

The NRC staff issued RAI-3 to request sensitivity studies on timestep size and vessel nodalization. The intent of this RAI was to obtain assurance that potential changes in discretization would not have an undue impact on calculated FoMs or change the sensitivities to statistical parameters.

In the RAI response, **[[** **]]** No clear trend was observed with respect to timestep size.

For the vessel nodalization study, **[[** **]]**

The range of the impact on core MCPR and ICO results is **[[**

**]]** provides sufficient justification for the NRC staff to conclude that the "base" vessel nodalization and timestep size parameter values used in ANP-10344P are acceptable for BEO-III analyses.

Core nodalization could potentially impact the BEO-III results as well for similar numerical damping considerations as mentioned above, as well as an impact related to resolving void fraction gradients in the bottom portion of the channel. A sensitivity study on core nodalization was not requested by the NRC staff in its review of Framatome's BEO-III methodology. However, such a study was performed for the ATWS-I methodology (Ref. 15), **[[** **]]**. For ATWS-I, a trend of **[[** **]]** was observed. However, the "base nodalization" of **[[** **]]** axial core nodes was found to be acceptable due to the good agreement it provided with the measured data, whereas **[[** **]]**. Because **[[** **]]**, the NRC staff expects a similar trend would be observed for BEO-III and the same conclusions would apply. Furthermore, the vessel nodalization study, in particular, and the timestep size study performed for BEO-III, would be expected to impact the solution in a similar way as a core nodalization study, at least in terms of the impact on numerical diffusion. Therefore, the NRC staff finds sufficient justification to conclude that the base axial nodalization of **[[** **]]** nodes for the BEO-III methodology is acceptable.

## 3.7 BEO-III Cycle-Specific Analyses

### 3.7.1 Statistical Methodology

The impact of code uncertainties on the 95/95 core MCPR and ICO results was evaluated by the applicant using a statistical process based on non-parametric order statistics. This is a well-established Monte Carlo-based statistical method, and implementations of this method have been approved by the NRC staff in the past, for example, in the AURORA-B AOO TR (Ref. 18). This method involves the following steps:

1. selection of a set of model parameters that is expected to provide the largest impact on the 95/95 results,
2. determination of applicable uncertainty values for these variables,
3. execution of a series of statistical trials using random perturbations of these variables within RAMONA5-FA, and
4. determination of the 95/95 results for the FoMs derived from these calculations.

The selection of largest-impact parameters was performed based on the BEO-III PIRT provided in Section 4.2, "PIRT Summary," of ANP-10344P. The applicant defined high probability as **[[** **]]** at least 95 percent of the population with 95 percent or greater confidence (95/95). The NRC staff has accepted use of the 95/95 criterion in numerous past reviews as providing sufficient confidence that safety limits and other regulatory criteria are satisfied.

In practice, the 95/95 value for each FoM is determined by sorting the FoM results from all statistical trials at a given exposure point and event condition. Then, the $N_{\text{th}}$ most limiting FoM value is selected, where $N$ is the acceptance number corresponding to a simultaneous upper tolerance limit with at least 95 percent probability coverage at a 95 percent confidence level for the predetermined statistical sample size. For BEO-III, the consequences of the limiting stability event(s) are determined to be acceptable if **[[ ]]** with 95 percent probability at 95 percent confidence. This means that if **[[ ]]**

The applicant noted that the required sample size for a given acceptance number is dependent upon the number of parameters being treated simultaneously. The NRC staff finds the statistical approach proposed for the ~~Brunswick-specific~~generic BEO-III methodology appropriately ensures **[[ ]]**

Based on its review, the NRC staff finds that the same overall statistical approach proposed in BEO-III was previously used in the approved AURORA-B AOO TR (Ref. 18). This statistical approach based on non-parametric order statistics provides a broad framework for determining the impact of code uncertainties on relevant FoMs, independent of the actual modeling details and FoMs specific to each application. Therefore, the NRC staff finds the proposed use of non-parametric order statistics to be acceptable for use in BEO-III, provided that the method is implemented appropriately to the BEO-III analyses.

To determine the appropriateness of the implementation, the NRC staff verified that the individual RAMONA5-FA calculations were performed in an acceptable manner. The calculations realistically modeled the system response during the entire event progression from the initiating pump trip until oscillation suppression, and the most limiting potential stability events were considered, as discussed in Section 3.3, “Scenario Identification,” of this SE. Furthermore, input assumptions, including the timestep size and nodalization, were found to be acceptable, as discussed in Section 3.6 of this SE.

Additionally, the NRC staff determined that the FoMs – both the core MCPR FoM and the ICO FoM, were selected appropriately within the BEO-III framework to ensure compliance with GDCs 10 and 12. In the absence of ICOs, the core MCPR FoM determines the limiting MCPR response in the core during oscillations. The ICO FoM is used to ensure that any ICOs that may occur during such events will not lead to a more limiting MCPR response, and therefore, challenge the SLMCPR. Core oscillations and ICOs are the two fundamental types of oscillatory phenomena in BWRs that may challenge the SLMCPR during anticipated stability events. The inclusion of these two FoMs allows the methodology to provide adequate assurance that the safety criteria are met for all anticipated oscillation types.

In summary, the applicant proposed an acceptable non-parametric order statistics process, applied this process to suitable stability analysis calculations, determined statistical parameters and uncertainties appropriately, and established acceptable FoMs to ensure that relevant safety limits are not violated. Thus, the NRC staff finds the statistical methodology proposed by the applicant is acceptable, provided that an appropriate calculation procedure is used to apply it to plant- and cycle-specific analyses. The calculation procedure is evaluated in the following section to confirm this condition is satisfied by the applicant.

### 3.7.2 BEO-III Calculation Procedure

Section 7.2 of ANP-10344 defines a calculation procedure that will be used on a cycle-specific basis to determine that stability events will not challenge the SLMCPR. A sample ATRIUM 11 equilibrium cycle analysis using this procedure was provided in ANP-10344P, Section 9.0, “ATRIUM Equilibrium Cycle Sample Application.”

Definition of Statepoints

The ANP-10344P, Section 7.2, calculation procedure defines the statepoints to be analyzed. **[[** **]]** The NRC staff finds the definition of exposure points to be acceptable **[[** **]]**

**[[** **]]** This is consistent with the previous methodologies and the NRC staff finds it remains acceptable for BEO-III. However, **[[** **]]** The NRC staff finds this acceptable because **[[** **]]** results in a more unstable core and the resulting FoM margins are expected to be bounding **[[** **]]**

The calculation procedure includes an **[[** **]]** The NRC staff finds the proposed **[[** **]]** to be acceptable based on the evaluation given in Section 3.9, “ATRIUM 11 Equilibrium Cycle Sample Application,” of this SE.

The calculation procedure proposes that three events **[[** **]]**

1. a two-pump trip from rated power at the lowest licensed core flow with nominal rated subcooling (EFW event),
2. a two-pump trip from rated power at the lowest licensed core flow that allows FWHOOS, with increased subcooling corresponding to the minimum allowed FW temperature (MELLLA FWHOOS event), and
3. a single-pump trip from the highest power under SLO, with nominal subcooling (SLO event).

**[[**

**]]**

The NRC staff expects the most limiting event in terms of final MCPR margin to be one of these three events, and inclusion of these events **[[ ]]** is consistent with Option III and EO-III. In general, oscillations will grow faster, and therefore, may exhibit the largest delta-MCPR response at the time of trip, at higher rod lines. The EFW event provides the highest allowable rod line at rated power and is likely to be the most limiting event. However, the growth rate of oscillations also increases with core inlet subcooling, so the MELLLA FWHOOS event shall be analyzed as well, as indicated in ANP-10344P Section 7.2. The SLO event is included because this case provides a smaller decrease in flow rate during the event, and therefore, a smaller initial increase in MCPR margin, relative to the TLO operating points. This may compensate for the slower oscillation growth rate expected for this case.

The stability characteristics and dynamic system response may change somewhat across typical reload cycles, but at least to a reasonable degree, such changes would be expected to have a similar impact on the results for all three events. **[[**

**]]** to be acceptable.

The NRC staff issued RAI-4 to request the description and justification for the process used to determine whether a BEO-III analysis remains bounding when actual cycle operation deviates significantly from the intended cycle design. In response, the applicant discussed its existing process for addressing deviations in cycle operation, starting with an assessment of whether the deviations are minor (i.e., negligible impact) or whether additional analyses are necessary to ensure the cycle licensing limits remain valid. Such analyses may include **[[ ]]** to ensure that the cycle analyses remain bounding. This is determined based on criteria defined in the reload safety analysis report, considering the impact on **[[ ]]** which are key phenomena affecting AOOs as well as stability analyses in particular. In the event that actual cycle operation is not expected to be protected by established operating limits, Framatome uses historic operating data and the projected depletion to end of cycle to establish new appropriate operating limits.

The NRC staff reviewed the information presented and finds this process for addressing unanticipated operating cycle changes to be reasonable and consistent with general industry practice. However, the representativeness of the specific historical operating data and depletion projections that may be used to address unanticipated operating cycle changes in future cycles is beyond the scope of the present review. In accordance with Generic Letter 88-16, “Removal of Cycle-Specific Parameter Limits from Technical Specifications,” and subject to the provisions of 10 CFR 50.59, “Changes, tests and experiments,” applicants typically perform cycle-specific core reload analyses without prior NRC staff review. By the same token, modifications to cycle-specific reload analyses to address unanticipated operating cycle changes may also be performed without prior NRC staff review if the provisions of 10 CFR 50.59 are satisfied. The NRC staff notes that changes made by applicants under the 10 CFR 50.59 process are subject to oversight through the NRC's inspection program. Therefore, the NRC staff finds that the applicant will appropriately address unanticipated changes and the cycle-specific BEO-III analyses will remain bounding or will be updated to appropriately account for unanticipated variations in cycle operation.

In addition, ANP-10344, Section 7.2, specifies that the RAMONA5-FA [[

**]]**. The NRC staff finds this acceptable because lower core flow rates promote more unstable oscillations; hence, this approach conservatively accounts for the differences between **[[**

**]]**

Confirmation of SLMCPR Protection

Under the procedure in ANP-10344P, Section 7.2, the OLMCPR is confirmed to protect the SLMCPR if **[[**

**]]** the methodology finds that the existing OLMCPR is adequate to protect against postulated core oscillations. Otherwise, the OLMCPR must be modified **[[** **]]** to protect the SLMCPR, or additional actions such as modification of the cycle design are required.

ICOs are significantly more likely for pump trips starting from the EFW domain, as these oscillations typically only occur deeper into the unstable region (upper left corner) of the power-flow map relative to core-wide oscillations. In the generic EO-III methodology, which is approved for EFWs (e.g., the EFW operating domain), ICOs were precluded by establishing a channel instability exclusion region. This was done because ICOs lead to a breakdown of the relationship between delta-MCPR and oscillation magnitude (i.e., DIVOM), which forms a central component of that methodology. Thus, it was determined that the methodology could not be guaranteed to protect the SLMCPR in the presence of ICOs.

Hypothetically, a similar philosophy for ICOs could have been adopted in BEO-III by **[[**

**]]**

The SLMCPR must be protected in the presence of full-core oscillations, ICOs, or both modes at once. **[[**

]] This could occur, hypothetically, by constructive interference depending on the timing and location of both modes in the core.

The applicant provided a discussion in Section 5.4.1, “Basis for the Independent Channel Oscillation,” and Section 8.1, [[ ]] of ANP-10344P [[ ]] The applicant discussed [[ ]]

This discussion agrees with the NRC staff’s understanding of the underlying stability phenomena and is further supported by the illustrative study provided in Section 5.4.1 of ANP-10344P. In this study, [[ ]] Although this is only one example for a particular BWR core and operating condition, it provides added confidence to the expectation that the multistage analysis approach is conservative.

Based on the discussions and illustrative example provided in ANP-10344P, the NRC staff concludes that the Stage 3 analysis will produce a conservative result for the ICO ~~MCPR response~~FoM. The Stage 3 calculation [[ ]] Therefore, the NRC staff finds the ICO ~~MCPR~~ FoM calculation method in ANP-10344P to be acceptable.

As evaluated above, the ANP-10344P methodology sufficiently ensures that the SLMCPR will not be violated when considering the possibility of full-core oscillations, ICOs, and the potential combination thereof. Thus, the NRC staff finds that the calculation procedure in ANP-10344P provides an acceptable means of demonstrating SLMCPR protection during all anticipated oscillation modes in the current fleet of BWRs.

### Minimum Oscillation Period

Plant-specific D&S algorithms based on the PBDA define a time period lower limit ($T_{min}$); any oscillations which have oscillation periods lower than this limit will not be identified as oscillations by the D&S algorithm. Therefore, such D&S algorithms cannot be assured to provide SLMCPR protection against such oscillations if they occur.

The BEO-III calculation procedure in Section 7.2 includes an analysis of a 1RPT scenario from the EFW operating point (lowest allowed flow rate at rated power), in order to provide assurance that no anticipated oscillations will have a period below $T_{min}$. This is determined by comparing the 95/95 lowest oscillation period to $T_{min}$, in order to account for calculation uncertainties. The 1RPT calculation will **[[**

**]]**

The oscillation period decreases with increasing flow rate; however, the DR also decreases with increasing flow rate. Therefore, considering progressively lower final flow rates, the lowest period is expected to occur at the flow rate at which the DR first exceeds 1.0. The NRC staff issued RAI-8 to obtain clarification on the approach to be used for the 1RPT analysis. In the response to RAI-8a, Framatome clarified that the EFW operating point (lowest allowed flow rate at rated power) would be used for the 1RPT minimum oscillation period analysis in all plant-specific applications. Based on the NRC staff's experience, the 1RPT event from the lowest-flow point of the EFW domain provides a reasonable approximation of this limiting condition, as it will result in lower oscillation periods than a 2RPT event from the same statepoint, provided that the 1RPT results in unstable oscillations at all. Therefore, the NRC staff finds this initial statepoint acceptable.

As discussed in the response to RAI-8b, in the event that the 1RPT from the EFW statepoint does not result in unstable oscillations, Framatome will **[[**

**]]** Therefore, the NRC staff finds this an acceptable method for ensuring that no anticipated oscillations will have a time period less than $T_{min}$.

### 3.7.3 Backup Stability Protection Calculation Procedure

In the event that the OPRM system is unavailable, backup stability protection (BSP) is used to ensure that core oscillations that may violate the safety limits will not occur. The BSP approach will be provided based on established BWROG definitions (Ref. 20) that have been used in previously approved Framatome stability methods (Ref. 9). The BSP curves will be evaluated using STAIF, a previous version of which was approved for calculating stability boundaries (Ref. 21) and is further used in previous stability methodologies such as EO-III (Ref. 9).

The version of STAIF used in the current methodology differs from the approved version only in the fuel models used. The BEO-III STAIF code uses the same **[[** **]]** fuel rod models as the BEO-III RAMONA5-FA code. These fuel models were found to be acceptable for both codes in Section 3.5.1, "Fuel Rod Models," of this SE. Because of this, and because BEO-

III does not impose any other changes to the BSP implementation, the NRC staff finds the implementation of BSP in ANP-10344P to be acceptable.

### 3.8 Identification of Major Conservatisms

Section 8.0, “Identification of Major Conservatisms,” of ANP-10344P describes inherent conservatisms in the methodology. One of the listed conservatisms relates to the **[[** **]]** which was evaluated in Section 3.7.2 of this SE.

Another listed conservatism is the use of the SLMCPR as a proxy SAFDL for stability events. The applicant discusses that recent large-amplitude oscillation data from the KATHY facility suggest that large cladding temperature excursions during oscillations are associated with a failure of the cladding outer surface to rewet, which happens later than the onset of boiling crisis. This would mean that the CPR-based fuel failure criterion used in the current and previous stability methodologies is conservative. These failure-to-rewet data and associated models were evaluated for the ATWS-I methodology of ANP-10346P. However, their use in the context of stability applications is beyond the scope of the current review, and the proposed BEO-III methodology uses conventional CPR-based fuel failure criteria.

The additional listed conservatisms regarding the **[[** **]]** have been addressed in previous sections of this evaluation. The NRC staff concludes that the BEO-III methodology employs a combination of best-estimate and conservative assumptions such that the final calculation of stability margins remains conservative overall.

### 3.9 ATRIUM 11 Equilibrium Cycle Sample Application

Sample Equilibrium Cycle Results

Sample BEO-III results for an ATRIUM 11 equilibrium cycle at a large BWR/3 plant were provided for illustration purposes in Section 9.0, “ATRIUM 11 Equilibrium Cycle Sample Application,” of ANP-10344P. For this sample cycle calculation, SLMCPR protection was successfully demonstrated for all three events. The FWHOOS was highly non-limiting, with a 95/95 core MCPR result of **[[** **]]** The EFW 2RPT event and the SLO event produced comparable 95/95 core MCPR values **[[** **]]** However, an OLMCPR of **[[** **]]** was used for all three cases, which appears to be a simplifying assumption in this sample analysis. In typical applications, the OLMCPR is expected to be significantly higher for SLO than for the TLO EFW conditions (as in the 2RPT event). If this were accounted for, the EFW 2RPT would likely have been the most limiting event by a significant margin, which aligns with the applicant’s expectations as stated in Section 7.2.

**[[**

]]

Based on the trends observed in the sample MELLLA+ cycle and on the NRC staff's understanding of cycle-dependent stability behavior, the 5 percent MCPR and 15 percent channel DR criteria are expected to capture the most limiting 95/95 exposure points with high confidence. This is especially true considering that both nominal and biased nominal parameters are analyzed, providing even more complete coverage of the expected trends with respect to exposure.

The NRC staff issued RAI-9 to determine whether the applicant intends to use the specific pre-filter approach provided in Section 9.0 on a generic basis or whether other approaches could be used. In the RAI response, the applicant clarified that this specific approach, including [[ ]] is intended for generic use. Because of the high likelihood of selecting the most limiting exposure points, the NRC staff finds the pre-filter process described in Section 9.0 to be acceptable for use on a generic basis.

However, although it is highly likely that this [[ ]] will identify the most limiting 95/95 exposure point, the trend in 95/95 limiting MCPR versus exposure could differ somewhat from the trends in the [[ ]] performing the statistical analyses on the reduced set of exposure points, the applicant should inspect the 95/95 results for these exposure points. If trends are observed which indicate that the most limiting exposure point(s) may be outside the analyzed range of exposures, additional exposure points should be analyzed until reasonable assurance is attained that the limiting exposure point is analyzed.

Minimum Oscillation Period

A 1RPT analysis from the EFW statepoint was run for the sample cycle to ensure that all anticipated oscillations have period values above $T_{min}$, as discussed in Section 3.7.2 of this SE. For this sample application, the 1RPT event remained stable. [[

]] This successfully demonstrates that all anticipated oscillations will occur within the PBDA stability detection limits for this sample application.

[[

]] As a result, the NRC staff would find this to be an acceptable means of determining the minimum oscillation period in plant-specific applications, in the situation where the unadjusted 1RPT event remains stable.

## 4.0 LIMITATIONS AND CONDITIONS

Section 11.0, “Limitations and Conditions,” of ANP-10344P included a list of eight proposed limitations and conditions. Proposed conditions 2, 6, 7, and 8, and the plant-specific component of condition 3, are consistent with the limitations and conditions imposed for the plant-specific BEO-III methodology in the approved Brunswick ATRIUM 11 fuel transition license amendment (Ref. 5). Proposed condition 4 as well as the component of condition 3 related to other noise methods was evaluated in Section 3.8, “Identification of Major Conservatisms,” of this SE. After review, the NRC staff finds the application of these conditions to be acceptable and appropriate, with the exception of proposed conditions 6 and 7, which are not necessary for the current evaluation. These two conditions were applied to the Brunswick review because they addressed topics which were not directly discussed in the Brunswick ATRIUM11 license amendment but only in RAIs and their responses; the NRC staff included these conditions in its SE to ensure acceptable treatment of these issues. However, in the generic BEO-III TR, Framatome modified the description of the methodology to ensure these issues will be acceptably addressed. Therefore, no additional conditions in this SE are required for these issues.

Proposed condition 1 relates to potential future changes to or replacement of MICROBURN-B2 as the core simulator and is appropriate because it ensures that changes to core simulator methods would be subject to technical review by the NRC staff.

Proposed condition 5 relates to potential future changes to the RAMONA5-FA code. While the NRC staff agrees that substantive model changes affecting the BEO-III analysis would require prior review by the NRC staff, the NRC staff does not agree with the applicant’s referencing of 10 CFR 50.59 with respect to changes made to fuel vendors’ codes or analysis methods. In fact, such application appears beyond the scope of the regulation, considering that 10 CFR 50.59(b) states that “[t]his section applies to each holder of an operating license issued under this part or a combined license issued under [P]art 52 of this chapter….” Moreover, because an assessment of methodology changes with respect to the criteria listed 10 CFR 50.59(c) may in general lead reactor licensees to different conclusions for different licensed facilities, there is no obvious means for a fuel vendor to make a singular judgment on behalf of all potentially affected licensees concerning the need for prior NRC staff review of a given methodology change. While the NRC staff does not directly regulate vendor modifications to analytical codes, changes to codes in general have the potential to affect evaluation models approved by the NRC staff. Therefore, the NRC staff has included a revised version of the applicant’s proposed condition 5 that is based upon the principle of maintaining the BEO-III methodology as described in the submittals the NRC staff has reviewed and which form the basis for the conclusions expressed in the present SE.

Framatome's proposed conditions for ANP-10344P address all stability-related conditions in the Brunswick ATRIUM 11 fuel transition SE with the exception of Brunswick BEO-III conditions 1 and 5. Brunswick BEO-III condition 1 requires that the **[[**

**]]** In ANP-10344P, the applicant provided additional detail on the Stage 3 **[[**

**]]** were defined by Framatome in the RAI-5 response, and the NRC staff's evaluation is given in Section 3.5.4 of this SE. Therefore, Brunswick BEO-III condition 1 does not need to be captured in the limitations and conditions for the generic BEO-III methodology.

Brunswick BEO-III condition 5 relates strictly to the use of the confirmation density algorithm as the D&S algorithm at Brunswick. This is a plant-specific issue which is not relevant to applications of BEO-III on a generic basis. Plant-specific applications which rely on PBDA as the D&S algorithm may use RAMONA5-FA and the built-in PBDA implementation to determine appropriate trip times using the plant-specific PBDA settings. Any plant-specific applications which rely on D&S algorithms other than PBDA are beyond the scope of this SE and would require a separate licensing action.

Therefore, the conditions proposed by the applicant in Section 11.0 of ANP-10344P are acceptable, with the modification discussed above to proposed condition 5, and with proposed conditions 6 and 7 being removed as unnecessary for the generic methodology. Framatome has appropriately addressed the conditions from the Brunswick plant-specific BEO-III application in this generic application. Furthermore, additional conditions 6 through ~~9~~ 8 have been imposed to address additional issues which were identified during the NRC staff's review of the generic BEO-III methodology described in ANP-10344P.

Application of BEO-III to New Fuel Types

ANP-10344P provides sample MELLLA+ results using ATRIUM 11 fuel; however, the applicant did not restrict application of the methodology to current fuel types. The NRC staff issued RAI-6 to obtain information on the applicant's intended process to apply BEO-III to new fuel types beyond ATRIUM 11. In the RAI response, Framatome discussed that the same approach will be used as for previous fuel introductions. This includes a review to determine whether current RAMONA5-FA modeling capabilities can adequately model the new fuel design features. If so, the existing modeling capabilities are considered appropriate **[[**

**]]** The NRC staff has determined that this approach remains applicable for BEO-III because it will ensure that the necessary additions to RAMONA5-FA are properly identified and incorporated with the introduction of new fuel types and that all physical phenomena necessary for accurate stability prediction will be appropriately updated to reflect the behavior of the new fuel type. Application of BEO-III to new fuel types is acceptable under this existing fuel development process. Through its existing regulatory processes, including inspection and review of licensing actions, the NRC staff retains appropriate oversight of vendor determinations concerning methods applications to new fuel products. Therefore, no additional limitation and condition is necessary to address this topic in the present SE.

Gap Conductance Sensitivity

The SE for ANP-10346P imposed a limitation that the gap sensitivity study must be repeated or otherwise justified for a transition to new fuel designs. As discussed in Section 3.5.1 of this SE, the fuel rod model impacts the thermal energy stored in the fuel rod and the heat that reaches the cladding surface and coolant during thermal-hydraulic oscillations. The gap width and associated gap conductance are important parameters in determining the dynamic thermal performance of the fuel during stability events.

New fuel designs, with changes to fuel geometry or materials, could potentially have different sensitivity to gap conductance than current fuel designs. Therefore, the NRC staff imposed the aforementioned limitation for ANP-10346P to ensure that the impact of gap conductance uncertainty for new fuel designs can be readily accommodated by the available margins in operator action time for ATWS-I events, and therefore that the ATWS-I consequences would remain acceptable.

However, such a limitation is not necessary for BEO-III because **[[**

**]]** and the resulting impact on the BEO-III FoMs, will be accounted for by the BEO-III methodology. Through its existing regulatory processes, including inspection and review of licensing actions, the NRC staff retains appropriate oversight of this issue. Therefore, no limitation is necessary with regard to gap sensitivity.

Limitations and Conditions

1. MICROBURN-B2 is an integral component in the BEO-III methodology. Application of a new core simulator requires review and approval by the NRC.

2. Selected settings and modeling options, including core and vessel nodalization and time step control parameters, shall be defined consistently with the validation basis presented in Section 6.0.

**3.** **[[**

**]]**

**4.** **[[**

**]]**

5. Framatome must continue to use existing regulatory processes for any code modifications made to the RAMONA-5FA code. The existing regulatory processes do not allow changes to the RAMONA5-FA code that would substantively alter the BEO-III methodology, as described in ANP-10344P and supporting RAI responses, which the

NRC staff relied upon as the basis for the finding of acceptability in this SE, without prior NRC review and approval.

6. Plant-specific applications shall justify whether the recirculation pump coastdown behavior will have a significant impact on the final MCPR for the specific plant and conditions being analyzed. If so, the uncertainties in the recirculation pump coastdown response should be included in the statistical analyses or otherwise accounted for.

7. If the 1RPT EFW event remains stable, additional analyses are required using **[[ ]]** to ensure that the lowest oscillation period remains above $T_{min}$ under any anticipated conditions.

8. After applying the **[[ ]]** If trends are observed which indicate that the most limiting exposure point(s) outside the analyzed range of exposures, additional exposure points should be analyzed until reasonable assurance is attained that the limiting exposure point is analyzed.

## 5.0 CONCLUSIONS

Based upon its review, the NRC staff finds that the generic BEO-III calculation procedure in ANP-10344P provides an acceptable means of determining licensing basis SLMCPR protection during anticipated stability events for the operating BWR fleet. As discussed in the foregoing evaluation, the NRC staff's conclusion relies upon the applicant adhering to the limitations and conditions enumerated above in Section 4.0 of this SE.

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15. Framatome, Inc., "ANP-10346P-A, Revision 0, 'ATWS-I Analysis Methodology for BWRs Using RAMONA5-FA'," ADAMS Accession No. ML20034E952, October 31, 2019.

16. Boiling Water Reactor Owners Group, "NEDO-31960-A, 'BWR Owners' Group Long-Term Stability Solutions Licensing'," November 1995.

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