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	Page	Line	Comment	
Number	Number	Number/s		
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 AURO		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	59 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 P		Information that should be marked as Proprietary is		
			highlighted in <mark>Yellow</mark> .	

1 DRAFT SAFETY EVALUATION FOR FRAMATOME INC. 2 3 **TOPICAL REPORT ANP-10344P, REVISION 0** 4 5 "FRAMATOME BEST-ESTIMATE ENHANCED OPTION III METHODOLOGY" 6 7 EPID L-2019-TOP-0046 8 9 **PROJECT NO. 728** 10 11 **DOCKET NO. 99902041** 12 13 14 1.0 INTRODUCTION 15 16 Framatome Inc. (Framatome) submitted Topical Report (TR) ANP-10344P, "Framatome BesteEstimate Enhanced Option III [(BEO-III)] Methodology," to the U. S. Nuclear Regulatory 17 18 Commission (NRC) on October 31, 2019 (Ref. 1). This TR is intended to support analysis of 19 stability for boiling water reactors (BWRs). 20 21 Following stability events that occurred at BWRs during the late 1980s (Ref. 2) and early 1990s 22 (Ref. 3), in response to NRC staff concerns, the industry made a number of improvements to 23 analytical methods, plant hardware, and plant operations. Among these improvements were 24 algorithms and associated analytical methods intended to allow detection and suppression of 25 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 26 27 Framatome's methods for analyzing stability. 28 29 In particular, Framatome's BEO-III methodology is similar to a plant-specific BEO-III approach 30 that the NRC staff has previously reviewed in a plant-specific license amendment to support a 31 transition to ATRIUM 11 fuel at the Brunswick Steam Electric Plant (Brunswick). This plant-32 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 33 34 for Brunswick to be acceptable as documented in Section 3.6, "Stability Analysis Using Plant-35 Specific Best-Estimate Option III (BEO-III) Approach," of its safety evaluation (SE) dated 36 March 6, 2020 (Ref. 5). 37 38 The description of the generic BEO-III stability methodology summarized in this SE is based 39 primarily upon Framatome's TR ANP-10344P, and a supporting response to a request for 40 additional information (RAI) dated November 30, 2020 (Ref. 6). 41 42 2.0 **REGULATORY EVALUATION** 43 The generic BEO-III methodology was developed to support a demonstration of BWR licensees'

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."

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49 Criterion 10, "Reactor design," requires that "The reactor core and associated coolant, control,

50 and protection systems shall be designed with appropriate margin to assure that specified

51 acceptable fuel design limits are not exceeded during any condition of normal operation,

- 52 including the effects of anticipated occurrences."
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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."

59 3.0 TECHNICAL EVALUATION

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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.
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• 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.

87 88 This approach of dividing the calculation process into three separate components introduces 89 significant conservatism into the calculation of operating limit MCPR (OLMCPR) values. For 90 example, because the statistical analysis component does not use best-estimate RAMONA5-FA 91 calculations to determine the core response during growing oscillations, the assumption is made 92 that the oscillations grow with a constant decay ratio (DR) from the time of oscillation inception 93 until suppression. Depending on statistical sampling, the constant DR value can be well 94 above 1.0. However, assuming a DR value significantly above 1.0 from the time of oscillation 95 inception is conservative. In a realistic recirculation pump trip (RPT) event, the oscillation 96 growth rate will begin at 1.0 at oscillation inception and gradually increase over time. This is 97 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. 98 99 These initially slower-growing oscillations increase the likelihood that sufficient successive 100 oscillation counts will be recorded by the period-based detection algorithm (PBDA) prior to the

102 of using a fixed oscillation DR leads to a conservatively high hot channel oscillation amplitude. 103 Another conservatism lies in the process of calculating the DIVOM slope, which determines the 104 MCPR response of fuel assemblies in the core under oscillatory conditions in a bounding (rather 105 than best-estimate) manner. 106 107 The EO-III methodology employs the same process as Option III for determining the core MCPR 108 response during anticipated oscillations. However, EO-III also calculates the limiting growth or DR for individual channel oscillations (ICOs) in the core. [[109 110 111 112]] The existence of ICOs simultaneously with 113 whole-core oscillations invalidates the assumptions of the DIVOM relationship and is unsuitable 114 under these conditions. Therefore, in conjunction with the normal DIVOM approach, EO-III 115 implements a scram region, known as the channel instability exclusion region, to ensure that the 116 power will be suppressed before ICOs may develop. 117 118 BEO-III discards the three-step approach used in Option III and EO-III. Instead, BEO-III 119 performs cycle-specific best-estimate RAMONA5-FA evaluations in which the entire event, 120 including the initiating pump trip and subsequent growth of oscillations, is explicitly modeled. 121 The event MCPR response and channel DRICO FoM are then determined to a 95/95 tolerance 122 limit to ensure adequate safety limit MCPR (SLMCPR) protection. These 95/95 values are 123 determined by performing a set of statistical trials in which physical modeling parameters are 124 randomly varied according to appropriate uncertainty distributions. 125 126 By explicitly modeling the plant and core response to the potentially limiting RPT events, 127 explicitly treating uncertainties through a statistical process, and directly calculating the MCPR 128 response from the oscillations that develop, many of the conservatisms inherent in the 129 three-step approach of Option III and EO-III are avoided. Best-estimate assumptions are made 130 for most of the modeling aspects of BEO-III; however, in some specific areas, Framatome made 131 conservative assumptions to ensure that the BEO-III predictions remain bounding with respect 132 to the safety criteria. 133 134 Many of the underlying modeling aspects of the BEO-III methodology remain the same relative 135 to Option III and EO-III. However, this is the first NRC review of a generic methodology in which 136 RAMONA5-FA is used within a statistical framework to determine the MCPR response and 137 associated uncertainty during stability events. Therefore, the NRC staff focused its review on 138 determining the acceptability of the new modeling features that were added to RAMONA5-FA. 139 as well as the acceptability of the statistical approach to ensure that the safety limits are met 140 during any anticipated oscillations in operating BWRs. 141 142 A plant-specific BEO-III methodology for the Brunswick described in ANP-3703P (Ref. 4) was 143 previously reviewed by the NRC staff and approved for Brunswick over an operating domain 144 that includes Maximum Extended Load Limit Line Analysis Plus (MELLLA+) (Ref. 5). The 145 Brunswick plant-specific BEO-III methodology is similar or identical to the generic BEO-III 146 methodology in ANP-10344P in many respects. The main difference between the two methods 147 is that for Brunswick, a separate post-processing step was necessary to simulate the behavior 148 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 149 150 used in the Brunswick application is not necessary. Consequently, the NRC staff's review of the

oscillations exceeding the amplitude setpoint. Accordingly, the Option III and EO-III assumption

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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.

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- 155 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"
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- 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
- 170 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."

- 177 3.3 Scenario Identification
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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

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

197 more limiting than the operating condition in the EFW domain due to the core inlet temperature 198 difference. 199 200 The methodology also evaluates a 1RPT event starting from the highest power level under 201 single-loop operation (SLO) conditions. This may be a limiting event because it results in flow at 202 natural circulation conditions similar to the 2RPT event. [[203 204]] 205 As stated in Section 7.2, "BEO-III Calculation Procedure," of ANP-10344P, the applicant 206 207 proposes to evaluate all three of these pump trip scenarios [[208 209]] 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 210 211 applications of Option III and EO-III. Therefore, the analysis of these three events in plant-212 specific applications is appropriate and sufficient. For scenarios which are non-limiting by a 213 significant margin above normal cycle variation, the applicant also proposes to [214 215]] The NRC staff's evaluation of this proposal is given in Section 3.7.2, "BEO-III Calculation Procedure." 216 217 218 3.4 **Evaluation Model Requirements** 219 220 RAMONA5-FA is currently approved for DIVOM analyses within the Option III and EO-III 221 methodologies. These DIVOM analyses involve calculation of the system stability response 222 starting from natural circulation conditions after the pump trip has completed. These analyses 223 must be able to accurately calculate the MCPR response as a function of oscillation amplitude 224 as the oscillations grow. However, the magnitude of oscillations that occur before they are 225 suppressed by a trip, is determined separately from the RAMONA5-FA calculations in these 226 previous methodologies. 227 228 The BEO-III methodology is used to determine [] 1 the MCPR 229 response during unstable oscillations, as in the Option III and EO-III methodologies. Therefore, the evaluation model requirements² related to the growth of oscillations and associated MCPR 230 231 response are the same for BEO-III as in these previous methodologies. 232 233 However, unlike the Option III and EO-III methodologies, the BEO-III RAMONA5-FA analyses 234 start from normal operating conditions and explicitly model the RPT and associated core inlet 235 flow and temperature response. Therefore, accurate modeling of the time-dependent plant 236 response following a RPT is required for BEO-III as well. Another difference is that BEO-III 237 implements the PBDA algorithm directly into RAMONA5-FA in order to simulate the OPRM 238 response and PBDA trip generation time for the time-dependent RAMONA5-FA 3D power 239 distribution. This requires that the PBDA algorithm be properly implemented, in order to 240 accurately determine trip times and resulting MCPR values for a given plant-specific application. 241 The applicant developed a phenomena identification and ranking table (PIRT) to determine 242 which model uncertainties are important in determining the core MCPR FoM and the ICO FoM 243 as defined in Section 2.0, "Regulatory Requirements Summary," of ANP-10344P (Ref. 1),

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).

- 244 "Regulatory Requirements Summary." This table summarizes all the relevant phenomena and
 245 provides an importance ranking with respect to each FoM. The NRC staff evaluated the BEO-III
 246 PIRT in detail due to its importance in determining the evaluation model requirements for
 247 BEO-III, as well as in defining the uncertainty parameters included in the statistical uncertainty
 248 analysis performed for BEO-III.
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250 Based on its review of the BEO-III PIRT, the NRC staff finds that the applicant identified all 251 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 252 253 neutronic and thermal-hydraulic dynamics of the core during oscillations, but also phenomena 254 that impact the plant and vessel response following a RPT. The NRC staff determined these 255 phenomena and their rankings to be consistent with the current state of understanding of BWR 256 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 257 258 NRC-published studies of ATWS-I scenarios (Ref. 12) and (Ref. 13), and other available 259 sources of information from open literature or internal NRC experience based on reviewing 260 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.

270 <u>Additional Potentially Significant Phenomena</u>271

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:

278]] • 279]] 280 281]]] 282 283 284 285]] The NRC staff finds that this assumption is conservative [[286 287 288 289]] Therefore, the NRC staff finds this treatment of [[290]] to be acceptable and finds that no *[[statistical sampling]]* of this parameter is needed. 291 292]] 293

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299 300 301		The NRC staff issued RAI-2 to obtain additional justification for [[]] as low importance, considering its physical relevance to stability dynamics. In particular, this [[
302 303 304 305 306 307	I]] 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.
307 308 309 310		In the RAI response, Framatome analyzed the behavior for [[
311 312 313 314 315]] 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.
316 317 318 319		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.
320		Core Flow and Power Uncertainty
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322 323 324		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.
325 326	1	In the RAI response, the applicant [[
327 328 329 330 331 332		
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 336 337 338 339 340 		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.
341 342 343		The NRC staff examined additional results in RAI-7 for a case that assumed a minimum flow and maximum power, [[

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351 352 353 354 355 356 357 358 359 360 361		The SLO [[
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363 364 365 366 367 368 369 370		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.
371 372 373 374	ļ	However, in Section 3.7.2 of this SE, the NRC staff concluded that the approach of [[
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377	ĺ	Considering that [[
378 379 380 381 382 383 384 385		II and the significant conservatism inherent in the channel MCPRICO 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.
385		3.5 Method Adaptations for BEO-III
387 388 389 390 391		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.
392 393		3.5.1 Fuel Rod Models

394 Fuel rod modeling impacts the thermal energy stored in the fuel rod and the heat that reaches 395 the cladding surface and coolant during thermal-hydraulic oscillations. Therefore, the BEO-III 396 model must adequately determine the initial condition of the fuel rod, the change in fuel rod 397 conditions following the initiating event (e.g., 2RPT), and the change in fuel rod conditions 398 during growing oscillations up until oscillations are suppressed by a scram. 399 400 For the BEO-III methodology, [[401 402 1] In the SE for ANP-10346P 403 (Ref. 15), the NRC staff concluded that the [[]] fuel rod model acceptably 404 simulates fuel behavior under the full range of conditions expected for ATWS-I. 405 406 Limiting ATWS-I events, such as 2RPT, are identical to stability events except that the ATWS-I 407 events are not terminated by a reactor scram. Therefore, the ATWS-I methodology must 408 determine the fuel rod behavior under the same conditions as for BEO-III, as well as under 409 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 410 411 (Ref. 5) can be used to justify the fuel rod model in the generic BEO-III methodology. 412 Additionally, the experimental benchmarking performed for BEO-III indicated no observable bias 413 that would indicate a deficiency in the fuel rod modeling. For these reasons, the NRC staff finds 414 that the [[]] fuel rod model is acceptable in both RAMONA5-FA and STAIF. 415 416 3.5.2 Radial Power Deposition Distributions in Fuel Pellets 417 418 The radial distribution of power deposition in the fuel pellets affects the fuel temperature 419 distribution and the rate of heat reaching the cladding and coolant as a function of time during 420 stability events. 421 422 423]] Therefore, the NRC staff finds the radial power deposition distribution model, which was found to be acceptable for [[424]] is acceptable for BEO-III 425 as well. 426 427 3.5.3 Period-Based Detection Algorithm Model 428 429 Framatome implemented the PBDA included in the Boiling Water Reactor Owners Group 430 (BWROG) Long-Term Stability Solutions Option III solution (Ref. 16) and (Ref. 17) within 431 RAMONA5-FA to determine the time of scram during the simulated oscillations. The NRC staff 432 reviewed Section 5.3, "Period-Based Detection Algorithm Model," of the TR and concluded that 433 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 434 435 calculations are consistent with those of the plant being analyzed. RAMONA5-FA calculates trip 436 times based on the PBDA only; application of BEO-III to a plant with a detect and suppress 437 (D&S) algorithm other than PBDA would therefore extend beyond the scope of the generic 438 BEO-III method being approved in the present SE. 439

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440 441	3.5.4 Multi-Stage Analysis
442	As in the Brunswick plant-specific methodology, the generic BEO-III methodology employs a
112	"multi stage analysis" approach to determine both the core MCPP and the ICO FoM for a given
443	statistical case. Due to its importance, the multi-stage analysis was a facus of significant
444	statistical case. Due to its importance, the multi-stage analysis was a locus of significant
440	allention during the NRC start's review. Details and the start's evaluation of each stage of the
440	multi-stage approach are provided below.
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457	The NRC staff evaluated [[]] to determine its ability to adequately determine [[
458]] as It of core oscillations during the limiting stability events. The
459	NRC staff determined that the limiting stability events were simulated in a realistic manner,
460	accounting for all important physics. [[
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469	I] The NRC staff finds that these best-estimate calculations were performed in an
470	acceptable manner and are suitable for use [[
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488	The NRC staff reviewed the [[]] and finds that it is
489	an acceptable means of determining [[

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501	specific information on the criteria that will be used for this determination. In the RAI response,
502	Framatome specified that the Stage 3 analysis [[
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507	The NRC staff finds this approach to be acceptable because II
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519	In the RAI-5 response, the applicant also provided [[
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532	The BEO-III methodology calculates []
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540 541 542 543 544 545 546 547	Ι	Figure 5-1, [[
548 549]] The example in Figure 5-1 provides added confidence that this is true, and therefore that the Stage 3 results are reliable and accurate.		
550 551 552 553 554 555 556 557 558 559		In RAI-1, the NRC staff requested a plot of core pressure drop [[
560 561 562]] Thus, the NRC staff finds that [[]] is acceptable.			
563 564 565 566 567		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 [[]]		
568 569		Based on these evaluations, the NRC staff finds that the core and ICO MCPR FoMs responses are adequately determined by the multistage analysis process.		
570 571 572		3.6 Code Validation and Model Uncertainties		
573 574 575 576		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.		
577 578		3.6.1 Model Uncertainties		
579 580 581 582 583 583		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.		
585 586 587 588 589		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

639 640 641		staff finds the methods used to determine uncertainties for all sampled parameters to be acceptable.
6/2		II uncertainties were derived based
643		on experimental void fraction data from the FRIGG and KATHY facilities. The FRIGG
644		experiments included legacy geometric designs, while the KATHY experiments included
645		benchmarking of ATRIUM-10 and ATRIUM 10XM fuel bundles. The [[
646] uncertainty was determined based on experimental pressure drop data from
647		KATHY for ATRIUM-10, ATRIUM 10XM, and ATRIUM 11 fuel. The ATRIUM-10 and
648		ATRIUM 10XM designs include part-length-fuel rods, mixing vane grids, and prototypic
649		axial/radial power distributions, which are reasonably representative of the design features in
650		ATRIUM 11.
651		
652		A sufficient degree of thermal-hydraulic compatibility with previous fuel types is a requirement
653		for introducing new fuel types. The NRC staff notes that bundle thermal-hydraulic parameters,
654		including pressure drop and void fraction distributions, depend primarily on bulk quantities such
655		as bundle hydraulic diameter and are relatively insensitive to mild variations in the configuration
656		of flow paths within the bundle. Therefore, the NRC staff finds it acceptable [[
657		
658	I]] Note that Section 4.0,
659		"Limitations and Conditions," of this SE provides the NRC staff's position on potential application
660		of BEO-III to new fuel types beyond ATRIUM 11.
661		
662		ll li l
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004 665		
666		
667		11 The NRC staff
668		finds this approach to be acceptable because [
669		
670		11
671		ſſ
672]] Realistic modeling of reactor noise is important
673		for stability calculations because it strongly affects the onset time and initial magnitude of
674		oscillations as the core becomes unstable. The model used to define this random noise,
675		including the values of parameters used to define the noise amplitude, as well as its temporal
676		characteristics, [[
677]] it is expected
678		to provide a realistic representation of the actual noise in terms of the distribution of amplitude
679		and frequency ranges within the noise signal. Additionally, the noise parameters to be used for
680		BEO-III analyses are consistent with those used for the validation cases, which provides
681		confidence that the BEO-III analyses will produce accurate results consistent with the good
682		experimental agreement demonstrated in ANP-10344P.
683		
684		However, the random nature of noise means that the results will differ depending on [[
685]] This may impact oscillation onset timing to some
686		degree, but the most significant effect is the possibility of PBDA resets due to the chaotic effects
687		of the applied noise. Such resets can significantly impact the PBDA trip time in each statistical

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 [[]] 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 exclusion of these phenomena is discussed in the following paragraphs.
 Interefore, the NRC staff finds the inclusion of [[I] to be acceptable. The NRC staff has determined that [[[] []<!--</td-->
1] Therefore, the NRC staff finds the inclusion of [[1] Therefore, the NRC staff finds the inclusion of [[1] The be acceptable. The NRC staff has determined that 1] [] to be acceptable. The NRC staff has determined that 1] [] </td
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698 [[699 700 701 702]] 703 704 Medium-Importance Phenomena Excluded from Sampling 705 706 The following medium-ranked parameters were omitted from the statistical sampling in the 707 ANP-10344P methodology: 708 • [[710 • 711 • 712 •]] 713 The exclusion of these phenomena is discussed in the following paragraphs. 715 [[716 [[717 1 718 1
699 I 700 J] 703 Medium-Importance Phenomena Excluded from Sampling 704 Medium-Importance Phenomena Excluded from Sampling 705 The following medium-ranked parameters were omitted from the statistical sampling in the 706 ANP-10344P methodology: 709 • [[711 • 712 • J] 713 714 714 The exclusion of these phenomena is discussed in the following paragraphs. 715 [[717 718
700 701 702]] 703 Medium-Importance Phenomena Excluded from Sampling 704 Medium-Importance Phenomena Excluded from Sampling 705 The following medium-ranked parameters were omitted from the statistical sampling in the 706 ANP-10344P methodology: 708 [[709 [[711 . 712 . 713]] 714 The exclusion of these phenomena is discussed in the following paragraphs. 715 [[717 . 718 .
701 [] 703 Medium-Importance Phenomena Excluded from Sampling 704 Medium-Importance Phenomena Excluded from Sampling 705 The following medium-ranked parameters were omitted from the statistical sampling in the 707 ANP-10344P methodology: 708 • [[710 • 711 • 712 •]] 713 The exclusion of these phenomena is discussed in the following paragraphs. 715 [[717 1 718 •
702]] 703 Medium-Importance Phenomena Excluded from Sampling 705 The following medium-ranked parameters were omitted from the statistical sampling in the 707 ANP-10344P methodology: 708 • 709 • 711 • 712 • 713 The exclusion of these phenomena is discussed in the following paragraphs. 715 [[717 18
 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.
Medium-Importance Phenomena Excluded from Sampling 705 706 707 708 709 709 711 712 713 714 715 715 716 717 718
 The following medium-ranked parameters were omitted from the statistical sampling in the ANP-10344P methodology: [[[[[] []
 The following medium-ranked parameters were omitted from the statistical sampling in the ANP-10344P methodology: 6 [[70 • [[71 •]] 71 •]] 71 The exclusion of these phenomena is discussed in the following paragraphs. 71 [[717 718
 ANP-10344P methodology: 708 709 • [[711 • 712 •]] 713 714 The exclusion of these phenomena is discussed in the following paragraphs. 715 716 [[717 718
708 709 [[710 • 711 • 712 •]] 713 714 The exclusion of these phenomena is discussed in the following paragraphs. 715 716 [[717 718
 709 10 710 711 712 713 714 714 The exclusion of these phenomena is discussed in the following paragraphs. 715 716 717 718
 710 711 712 713 714 The exclusion of these phenomena is discussed in the following paragraphs. 715 716 [[717 718
 711 712 713 714 The exclusion of these phenomena is discussed in the following paragraphs. 715 716 [[717 718
 712 • JJ 713 The exclusion of these phenomena is discussed in the following paragraphs. 715 The exclusion of these phenomena is discussed in the following paragraphs. 716 [[717 718 - 100 -
 713 714 The exclusion of these phenomena is discussed in the following paragraphs. 715 716 [[717 718
 714 The exclusion of these phenomena is discussed in the following paragraphs. 715 716 [[717 718
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/35 I ne NKC statt reviewed [[]] modeling approach and finds it 726 appontable that MICROPHEN P2 contains sufficient modeling fidulity to approach and finds it
730 acceptable that MICRODURIN-DZ contains sufficient modeling lidelity to accurately predict []

738	
739	11. The NDC staff finds that this imposet is small support that this measure the measure f
740	I The NRC start finds that this impact is small enough that this parameter may be
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742	Inal Folds.
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750	11
751	11
10Z	In Section 6.0. II
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754 755	
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158	11. The NDO staff finds that II
759	II The NRC start linds that [[
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701	
762	11
703	In addition to the impact of hyperse flow rate on the thermal hydroulis stability of the same the
704	In addition to the impact of bypass now rate on the thermal-hydraulic stability of the core, the
705	INRO stall considered the impact of bypass voluing and its effect of OPRM miscalibration. At
700	ospecially low flow rate, which can load to beiling in the upper parties of the bypass exhibits an
768	direct gamma heating and neutrons slowing down in the bypass. The resulting void formation in
760	the hypass reduces the sensitivity of the local power range monitors, which leads to error in the
709	measured local power level and resulting miscalibration of the OPPM signal
771	measured local power level and resulting miscalibration of the OF Mill Signal.
772	In its review of the EO-III methodology (Ref. 19) the NRC staff concluded II
773	
77/	
775	
776	11
777	11
778	Because BEO-III relies on the same D&S algorithm as EO-III, based on relative OPRM
779	amplitude signals, the same conclusion applies, and [[1]
780	necessary to account for OPRM miscalibration
781	
782	Note that average power range monitor (APRM) miscalibration due to bypass voiding does
783	impact the channel stability exclusion region of FO-III as discussed in the SF for ANP-10262PA
784	(Ref. 19). However, BEO-III does not calculate an exclusion region on the power-flow map.
785	instead, the impact of ICOs is evaluated within the multistage analysis supporting BEO-III
786	implementation. This does not involve detection of ICOs using plant hardware, and therefore
787	the miscalibration of APRMs and/or OPRMs due to bypass voiding is not relevant for this

788 789 790	determination. [[]] Note also that the impact of core power and flow unce Section 3.4, "Evaluation Model Requirements," and that [[ertainties was discussed in
792 793	l 11	
794 705		11 of
795	II IN Section 6.11, [[]] Of
790	ANP-10344P, the applicant indicated that []	
798		
799		
800		
801		
802		
803]] Therefore
804	the NRC staff finds that [[]] can be a	acceptably excluded from
805	the [[]]	
806		
807	The recirculation pump coastdown behavior affects the time required	for the core flow rate to
808	decrease to natural circulation conditions following a pump trip. If thi	s time is sufficiently long,
809	the elevated flow rates may delay the onset and early growth behavio	or of oscillations. This
010	could cause a significant change in oscillation period from one oscillation period fro	allon to the next; if this
011	may cause the PBDA successive escillation counts to result resulting	nin a possible delay in the
01Z 012	may cause the PBDA successive oscillation counts to reset, resulting	In a possible delay in the
013 81/	eventual PBDA trip signal timing.	
815	l rr	
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825		
826	Because of this peoplihility, the NDC staff issued DAI 10 to obtain add	litional instification for the
827	Because of this possibility, the NRC staff issued RAI-10 to obtain add	
020 820		IYSIS. [[
830		
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833		
834		11
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836	The NRC staff finds this approach to be acceptable [[
837		

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

Category	Parameter	PIRT Importance
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	+	-
	-	-
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3.6.2 Impact of Core Oscillation Mode

852 853 854 855 856 857	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.
858 859 860	[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. [
861 862 863	
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865	
866	
867	
868	
869	
070 871	
872	
873	
874	
875	
876	
877]] The [[]] was evaluated in Section 3.4 of this
878	SE and its exclusion from statistical sampling was found to be acceptable. The [[
879]] are included in the statistical sampling.
880	
881	Based on these findings, the NRC staff has determined that the appropriate phenomena were
882 002	the TeMe, under all antigipated experting conditions
00J 991	the Pows, under all anticipated operating conditions.
885	3.6.3 Additional Code Validation
886	
887	The validation of RAMONA5-FA against KATHY void fraction and pressure drop data is
888	discussed and evaluated in the previous section. Additional experimental benchmarking was
889	performed against measured stability data. These include KATHY stability tests, KATHY
890	dryout/rewet tests, linear reactor stability benchmarks, and a nonlinear reactor stability
891	benchmark. The tests encompass a wide range of conditions that provide sufficient coverage of
892	the expected core conditions during anticipated oscillations at BWRs.
893	
894	These stability benchmarks were also performed for the generic RAMONA5-FA ATWS-I
895	methodology described in ANP-10346PA (Ref. 15). The benchmarks include experimental
896 007	validation for the onset of oscillations, growth of oscillations, occurrence of dryout, and
091 091	POSI-UIYOUL DEHAVIOL. III ILS TEVIEW OF ANY-10340PA, THE INKU STAIL CONCIUDED THAT THE
800	this benchmarking was sufficient to justify the use of the RAMONA5-FA ATW/S-I code for
900	ATWS-I applications.

- 20 -

902 903 904 905 906		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
907 908		determine upper 95/95 bounds for DRs, frequencies, and other results across these benchmarks when relevant statistical parameters were considered. The statistical perturbations
909 910		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
911 912]] However, as discussed in its review of
913 01/		unaccentable discremancy in [[]] unu not read to an
015		NRC staff finds that the applicant's BEO-III methodology including treatment of uncertainties is
916 917		acceptable because its modeling result for the stability response and dryout occurrence during anticipated instability events is consistent with the measured data.
918 919		3.6.4 Timestep Size and Nodalization
920		
921		Spatial and temporal discretization may impact the stability behavior predicted by system
922		thermal-hydraulic codes such as RAMONA5-FA. It is often found that increasing the timestep
923		size leads to increased oscillation DRs, regardless of oscillation mode due to reduction in
924		numerical damping. Increasing the number of axial nodes in the core may have a similar effect
925		by reducing the numerical damping, as well as increasing the spatial resolution. However,
926		increasing the number of axial nodes in the vessel is only expected to have a significant effect
921 020		therefore, the flow rate in the vessel nodes, in essentially constant during out of phase
920 020		oscillations. In either case, vessel nodelization may also impact the core inlet subcooling by
929		affecting the transport of fluid energy through the vessel as the FW temperature decreases
930 931		during the event
932		
933		The NRC staff issued RAI-3 to request sensitivity studies on timestep size and vessel
934		nodalization. The intent of this RAI was to obtain assurance that potential changes in
935		discretization would not have an undue impact on calculated FoMs or change the sensitivities to
936		statistical parameters.
937		
938		In the RAI response, [[
939		
940		
941		
942]] No clear trend was observed with
943		respect to timestep size.
944		
945		For the vessel nodalization study, [[
946		
947 040		11
940 010		11
949 950 951		The range of the impact on core MCPR and ICO results is [[

952	
953	
954	
955	
956	11 provides sufficient justification for the NRC staff to conclude that the
957	"hase" vessel nodalization and timesten size parameter values used in ANP-10344P are
958	accentable for BEO-III analyses
959	
960	Core podalization could potentially impact the BEO-III results as well for similar numerical
961	damning considerations as mentioned above, as well as an impact related to resolving void
962	fraction gradients in the bottom portion of the channel. A sensitivity study on core podalization
963	was not requested by the NRC staff in its review of Framatome's BEO-III methodology
964	However, such a study was performed for the ATW/S-I methodology (Ref. 15) []
965	11 For ATWS-L a trend of
966	II was observed. However, the "base
967	nodalization" of [[]] avial core nodes was found to be accentable due to the good
968	agreement it provided with the measured data, whereas II
969	
970	J]: Decause [[1] the NRC staff
971	expects a similar trend would be observed for BEO-III and the same conclusions would apply
972	Furthermore, the vessel nodalization study in particular, and the timestep size study performed
973	for BEO-III would be expected to impact the solution in a similar way as a core nodalization
974	study, at least in terms of the impact on numerical diffusion. Therefore, the NRC staff finds
975	sufficient justification to conclude that the base axial nodalization of [[1] nodes for the
976	BEO-III methodology is acceptable.
977	
978	3.7 BEO-III Cycle-Specific Analyses
979	
980	3.7.1 Statistical Methodology
981	
982	The impact of code uncertainties on the 95/95 core MCPR and ICO results was evaluated by
983	the applicant using a statistical process based on non-parametric order statistics. This is a
984	well-established Monte Carlo-based statistical method, and implementations of this method
985	have been approved by the NRC staff in the past, for example, in the AURORA-B AOO TR
986	(Ref. 18). This method involves the following steps:
987	
988	1. selection of a set of model parameters that is expected to provide the largest impact on
989	the 95/95 results,
990	2. determination of applicable uncertainty values for these variables,
991	3. execution of a series of statistical trials using random perturbations of these variables
992	within RAMONA5-FA, and
993	4. determination of the 95/95 results for the FoMs derived from these calculations.
994	The selection of leavest investment of a second
995	ine selection of largest-impact parameters was performed based on the BEO-III PIRT provided
990 007	IN SECTION 4.2, FIRE SUMMARY, OF ANY-10344F. The applicant defined high probability as
991 000	IL Jat least 30 percent or greater confidence (05/05). The NPC staff has accounted use of
990 000	the 05/05 criterion in numerous past rovious as providing sufficient confidence that acfety limits
399 1000	and other regulatory criteria are satisfied
1000	
1001	

1002 In practice, the 95/95 value for each FoM is determined by sorting the FoM results from all 1003 statistical trials at a given exposure point and event condition. Then, the N_{th} most limiting FoM 1004 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 1005 the predetermined statistical sample size. For BEO-III, the consequences of the limiting stability 1006 1007 event(s) are determined to be acceptable if [[]] with 1008 95 percent probability at 95 percent confidence. This means that if [] 1009 11 1010 The applicant noted that the required sample size for a given acceptance number is dependent 1011 upon the number of parameters being treated simultaneously. The NRC staff finds the 1012 statistical approach proposed for the Brunswick-specific generic BEO-III methodology 1013 appropriately ensures 1014 11]] 1015 1016 Based on its review, the NRC staff finds that the same overall statistical approach proposed in 1017 BEO-III was previously used in the approved AURORA-B AOO TR (Ref. 18). This statistical 1018 approach based on non-parametric order statistics provides a broad framework for determining 1019 the impact of code uncertainties on relevant FoMs, independent of the actual modeling details 1020 and FoMs specific to each application. Therefore, the NRC staff finds the proposed use of 1021 non-parametric order statistics to be acceptable for use in BEO-III, provided that the method is 1022 implemented appropriately to the BEO-III analyses. 1023 1024 To determine the appropriateness of the implementation, the NRC staff verified that the 1025 individual RAMONA5-FA calculations were performed in an acceptable manner. The 1026 calculations realistically modeled the system response during the entire event progression from 1027 the initiating pump trip until oscillation suppression, and the most limiting potential stability 1028 events were considered, as discussed in Section 3.3, "Scenario Identification," of this SE. 1029 Furthermore, input assumptions, including the timestep size and nodalization, were found to be 1030 acceptable, as discussed in Section 3.6 of this SE. 1031 1032 Additionally, the NRC staff determined that the FoMs – both the core MCPR FoM and the ICO 1033 FoM, were selected appropriately within the BEO-III framework to ensure compliance with 1034 GDCs 10 and 12. In the absence of ICOs, the core MCPR FoM determines the limiting MCPR 1035 response in the core during oscillations. The ICO FoM is used to ensure that any ICOs that 1036 may occur during such events will not lead to a more limiting MCPR response, and therefore, 1037 challenge the SLMCPR. Core oscillations and ICOs are the two fundamental types of 1038 oscillatory phenomena in BWRs that may challenge the SLMCPR during anticipated stability 1039 events. The inclusion of these two FoMs allows the methodology to provide adequate 1040 assurance that the safety criteria are met for all anticipated oscillation types. 1041 1042 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.

1050 3.7.2 BEO-III Calculation Procedure

1051 1052 1053 1054 1055	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."
1056 1057	Definition of Statepoints
1058	
1059 1060 1061 1062 1063 1064 1065	The ANP-10344P, Section 7.2, calculation procedure defines the statepoints to be analyzed. [[
1000	
1068	
1069	
1070	definition of exposure points to be acceptable II
1071	
1073	"
1074	[[
1075]] This is consistent with the previous methodologies and the
1070	NRC stair linds it remains acceptable for BEO-III. However, []
1078]] The NRC staff finds this acceptable because
1079	[[]] results in a more unstable core and the resulting FoM margins are
1080	expected to be bounding [[]]
1081	The calculation procedure includes an II
1082	
1084	
1085]] The NRC staff finds the proposed
1086	[[]] to be acceptable based on the evaluation given in Section 3.9, "ATRIUM 1"
1087	Equilibrium Cycle Sample Application, of this SE.
1089	The calculation procedure proposes that three events [[
1090	
1091	1]
1092	1 a two-nump trip from rated power at the lowest licensed core flow with nominal rated
1094	subcooling (EFW event),
1095	2. a two-pump trip from rated power at the lowest licensed core flow that allows FWHOOS,
1096	with increased subcooling corresponding to the minimum allowed FW temperature
1097	(MELLLA FWHOUS event), and 3 a single-nump trip from the highest power under SLO, with pominal subcooling (SLO
1090	o. a single-pump inp nom me nignest power under SLO, with nominal subcooling (SLO event).
1100	- · · · · · · · · · · · · · · · · · · ·

1101	[[
1102 1103 1104	11
1104 1105 1106 1107 1108 1109 1110 1111 1112 1113 1114 1115 1116	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.
1117 1118 1119 1120 1121	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. [[
1122]] to be acceptable.
1125 1126 1127 1128 1129 1130 1131 1132 1133 1134	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
1135 1136 1137 1138	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.
1139 1140 1141 1142 1143 1144 1145 1146 1147 1148 1149 1150	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

1151	applicant will appropriately address unanticipated changes and the cycle-specific BEO-III
1152	analyses will remain bounding or will be updated to appropriately account for unanticipated
1153	variations in cycle operation.
1154	
1155	In addition, ANP-10344, Section 7.2, specifies that the RAMONA5-FA [[
1156	
1157	
1158]]. The NRC staff finds this acceptable
1159	because lower core flow rates promote more unstable oscillations; hence, this approach
1160	conservatively accounts for the differences between []
1161	
1162	11
1163	
1164	Confirmation of SI MCPR Protection
1165	
1166	Under the procedure in ANP-10344P. Section 7.2, the OLMCPR is confirmed to protect the
1167	SI MCPR if []
1168	
1160	
1170	
1171	
1172	
1172	
1173	
1174	
1175	
1170	
11//	11 the methodology finds that the existing
1170	II the methodology linds that the existing
11/9	DLINGPR is adequate to protect against postulated core oscillations. Otherwise, the OLINGPR
1100	indust be modification of the cycle design are required
1101	actions such as modification of the cycle design are required.
1102	1000 are significantly more likely for numerating starting from the EEW domain, as these
1100	cosillations typically only accur deeper into the unstable region (upper left corner) of the
1104	oscillations typically only occur deeper into the unstable region (upper left corner) of the
1100	power-now map relative to core-wide oscillations. In the generic EO-III methodology, which is
1180	approved for EFVVS (e.g., the EFVV operating domain), ICOS were precluded by establishing a
1187	channel instability exclusion region. This was done because ICOs lead to a breakdown of the
1188	relationship between delta-MCPR and oscillation magnitude (i.e., DIVOM), which forms a
1189	central component of that methodology. Thus, it was determined that the methodology could
1190	not be guaranteed to protect the SLMCPR in the presence of ICOs.
1191	I hundhetieelly, e similer shilesenby for 100s sould have been adouted in DEO. III hu
1192	
1193	u
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1196	
1197	1]
1198	
1199	The SLMCPR must be protected in the presence of full-core oscillations, ICOs, or both modes
1200	at once.

1201 1202 1203 1204	
1205 1206 1207]] This could occur, hypothetically, by constructive interference depending on the timing and location of both modes in the core.
1207 1208 1209 1210	The applicant provided a discussion in Section 5.4.1, "Basis for the Independent Channel Oscillation," and Section 8.1, [[]] of ANP-10344P [[
1211 1212 1213 1214 1215 1216 1217]] The applicant discussed [[
1218	11
1219 1220 1221 1222 1223 1224 1225 1226 1227 1228 1229 1230	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, [[
1231 1232 1233 1234]] 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.
1235 1236 1237 1238 1239	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 responseFoM. The Stage 3 calculation [[
1240 1241 1242]] Therefore, the NRC staff finds the ICO MCPR FoM calculation method in ANP-10344P to be acceptable.
1242 1243 1244 1245 1246 1247 1249	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.
1240 1249 1250	Minimum Oscillation Period

1251 Plant-specific D&S algorithms based on the PBDA define a time period lower limit (T_{min}); any 1252 oscillations which have oscillation periods lower than this limit will not be identified as 1253 oscillations by the D&S algorithm. Therefore, such D&S algorithms cannot be assured to 1254 provide SLMCPR protection against such oscillations if they occur. 1255 1256 The BEO-III calculation procedure in Section 7.2 includes an analysis of a 1RPT scenario from 1257 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 1258 1259 the 95/95 lowest oscillation period to T_{min}, in order to account for calculation uncertainties. The 1260 1RPT calculation will [] 1261]] 1262 1263 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 1264 1265 period is expected to occur at the flow rate at which the DR first exceeds 1.0. The NRC staff 1266 issued RAI-8 to obtain clarification on the approach to be used for the 1RPT analysis. In the 1267 response to RAI-8a, Framatome clarified that the EFW operating point (lowest allowed flow rate 1268 at rated power) would be used for the 1RPT minimum oscillation period analysis in all plant-1269 specific applications. Based on the NRC staff's experience, the 1RPT event from the lowest-1270 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 1271 1272 that the 1RPT results in unstable oscillations at all. Therefore, the NRC staff finds this initial 1273 statepoint acceptable. 1274 1275 As discussed in the response to RAI-8b, in the event that the 1RPT from the EFW statepoint 1276 does not result in unstable oscillations, Framatome will [[1277 1278 1279 1280 1281 1282 1283 **11** Therefore, the NRC staff finds this an acceptable method for ensuring that no anticipated oscillations will have a time period less than 1284 1285 T_{min}. 1286 1287 3.7.3 Backup Stability Protection Calculation Procedure 1288 1289 In the event that the OPRM system is unavailable, backup stability protection (BSP) is used to 1290 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 1291 1292 previously approved Framatome stability methods (Ref. 9). The BSP curves will be evaluated 1293 using STAIF, a previous version of which was approved for calculating stability boundaries (Ref. 1294 21) and is further used in previous stability methodologies such as EO-III (Ref. 9). 1295 1296 The version of STAIF used in the current methodology differs from the approved version only in 1297 the fuel models used. The BEO-III STAIF code uses the same [] 11 fuel rod 1298 models as the BEO-III RAMONA5-FA code. These fuel models were found to be acceptable for 1299 both codes in Section 3.5.1, "Fuel Rod Models," of this SE. Because of this, and because BEO-

1300 III does not impose any other changes to the BSP implementation, the NRC staff finds the
1301 implementation of BSP in ANP-10344P to be acceptable.
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1303 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 [[
minute state state

1309 Another listed conservatism is the use of the SLMCPR as a proxy SAFDL for stability events. 1310 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 1311 1312 failure of the cladding outer surface to rewet, which happens later than the onset of boiling 1313 crisis. This would mean that the CPR-based fuel failure criterion used in the current and 1314 previous stability methodologies is conservative. These failure-to-rewet data and associated 1315 models were evaluated for the ATWS-I methodology of ANP-10346P. However, their use in the 1316 context of stability applications is beyond the scope of the current review, and the proposed 1317 BEO-III methodology uses conventional CPR-based fuel failure criteria.

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1319 The additional listed conservatisms regarding the [[

1320]] have been addressed in previous sections1321of this evaluation. The NRC staff concludes that the BEO-III methodology employs a1322combination of best-estimate and conservative assumptions such that the final calculation of1323stability margins remains conservative overall.

- 1325 3.9 ATRIUM 11 Equilibrium Cycle Sample Application
- 1327 Sample Equilibrium Cycle Results

1329 Sample BEO-III results for an ATRIUM 11 equilibrium cycle at a large BWR/3 plant were 1330 provided for illustration purposes in Section 9.0, "ATRIUM 11 Equilibrium Cycle Sample 1331 Application," of ANP-10344P. For this sample cycle calculation, SLMCPR protection was 1332 successfully demonstrated for all three events. The FWHOOS was highly non-limiting, with a]] The EFW 2RPT event and the SLO event produced 1333 95/95 core MCPR result of [] 1334 comparable 95/95 core MCPR values [[]] However, an 1335]] was used for all three cases, which appears to be a simplifying assumption OLMCPR of [1336 in this sample analysis. In typical applications, the OLMCPR is expected to be significantly 1337 higher for SLO than for the TLO EFW conditions (as in the 2RPT event). If this were accounted 1338 for, the EFW 2RPT would likely have been the most limiting event by a significant margin, which 1339 aligns with the applicant's expectations as stated in Section 7.2.

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1370		Based on the trends observed in the sample MELLLA+ cycle and on the NRC staff's
1371		understanding of cycle-dependent stability behavior, the 5 percent MCPR and 15 percent
1372		channel DR criteria are expected to capture the most limiting 95/95 exposure points with high
1373		confidence. This is especially true considering that both nominal and biased nominal
1374		parameters are analyzed, providing even more complete coverage of the expected trends with
1375		respect to exposure.
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1377		The NRC staff issued RAI-9 to determine whether the applicant intends to use the specific
1378		pre-filter approach provided in Section 9.0 on a generic basis or whether other approaches
1379		could be used. In the RAI response, the applicant clarified that this specific approach, including
1380	I	Il is intended for generic use. Because of
1381	I	the high likelihood of selecting the most limiting exposure points, the NRC staff finds the pre-
1201		filter process described in Section 0.0 to be accontable for use on a generic basis
1002		liner process described in Section 9.0 to be acceptable for use on a generic basis.
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1384		However, although it is highly likely that this [[]] will identify the most limiting
1385	i	95/95 exposure point, the trend in 95/95 limiting MCPR versus exposure could differ somewhat
1386		from the trends in the []
1387]] performing the statistical analyses on the reduced set of exposure points, the applicant
1388		should inspect the 95/95 results for these exposure points. If trends are observed which
1389		indicate that the most limiting exposure point(s) may be outside the analyzed range of
1390		exposures, additional exposure points should be analyzed until reasonable assurance is
1391		attained that the limiting exposure point is analyzed.
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1393		Minimum Oscillation Period
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1395		A 1RPT analysis from the EFW statepoint was run for the sample cycle to ensure that all
1396		anticipated oscillations have period values above T as discussed in Section 3.7.2 of this SE
1307	ļ	For this sample application, the 1RPT event remained stable.
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11 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.

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4.0 LIMITATIONS AND CONDITIONS

1415 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 1416 1417 of condition 3, are consistent with the limitations and conditions imposed for the plant-specific 1418 BEO-III methodology in the approved Brunswick ATRIUM 11 fuel transition license amendment 1419 (Ref. 5). Proposed condition 4 as well as the component of condition 3 related to other noise 1420 methods was evaluated in Section 3.8, "Identification of Major Conservatisms," of this SE. After 1421 review. the NRC staff finds the application of these conditions to be acceptable and appropriate, 1422 with the exception of proposed conditions 6 and 7, which are not necessary for the current 1423 evaluation. These two conditions were applied to the Brunswick review because they 1424 addressed topics which were not directly discussed in the Brunswick ATRIUM11 license 1425 amendment but only in RAIs and their responses; the NRC staff included these conditions in its 1426 SE to ensure acceptable treatment of these issues. However, in the generic BEO-III TR, 1427 Framatome modified the description of the methodology to ensure these issues will be 1428 acceptably addressed. Therefore, no additional conditions in this SE are required for these 1429 issues.

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1431 Proposed condition 1 relates to potential future changes to or replacement of MICROBURN-B2 1432 as the core simulator and is appropriate because it ensures that changes to core simulator 1433 methods would be subject to technical review by the NRC staff.

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1435 Proposed condition 5 relates to potential future changes to the RAMONA5-FA code. While the 1436 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 1437 1438 10 CFR 50.59 with respect to changes made to fuel vendors' codes or analysis methods. In 1439 fact, such application appears beyond the scope of the regulation, considering that 10 CFR 1440 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 1441 1442 assessment of methodology changes with respect to the criteria listed 10 CFR 50.59(c) may in 1443 general lead reactor licensees to different conclusions for different licensed facilities, there is no 1444 obvious means for a fuel vendor to make a singular judgment on behalf of all potentially affected 1445 licensees concerning the need for prior NRC staff review of a given methodology change. While 1446 the NRC staff does not directly regulate vendor modifications to analytical codes, changes to 1447 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 1448

1449 that is based upon the principle of maintaining the BEO-III methodology as described in the 1450 submittals the NRC staff has reviewed and which form the basis for the conclusions expressed 1451 in the present SE. 1452 1453 Framatome's proposed conditions for ANP-10344P address all stability-related conditions in the 1454 Brunswick ATRIUM 11 fuel transition SE with the exception of Brunswick BEO-III conditions 1 1455 and 5. Brunswick BEO-III condition 1 requires that the [] 1456 1457 1] In ANP-10344P, the applicant provided additional detail on the Stage 1458 3 [[1459]] were defined by 1460 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 1461 limitations and conditions for the generic BEO-III methodology. 1462 1463 1464 Brunswick BEO-III condition 5 relates strictly to the use of the confirmation density algorithm as 1465 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 1466 1467 the D&S algorithm may use RAMONA5-FA and the built-in PBDA implementation to determine 1468 appropriate trip times using the plant-specific PBDA settings. Any plant-specific applications 1469 which rely on D&S algorithms other than PBDA are beyond the scope of this SE and would 1470 require a separate licensing action. 1471 1472 Therefore, the conditions proposed by the applicant in Section 11.0 of ANP-10344P are 1473 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 1474 1475 has appropriately addressed the conditions from the Brunswick plant-specific BEO-III 1476 application in this generic application. Furthermore, additional conditions 6 through 9-8 have 1477 been imposed to address additional issues which were identified during the NRC staff's review 1478 of the generic BEO-III methodology described in ANP-10344P. 1479 1480 Application of BEO-III to New Fuel Types 1481 1482 ANP-10344P provides sample MELLLA+ results using ATRIUM 11 fuel; however, the applicant 1483 did not restrict application of the methodology to current fuel types. The NRC staff issued RAI-6 1484 to obtain information on the applicant's intended process to apply BEO-III to new fuel types 1485 beyond ATRIUM 11. In the RAI response, Framatome discussed that the same approach will 1486 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, 1487 1488 the existing modeling capabilities are considered appropriate [1489 1490]] The NRC staff has determined that this approach remains 1491 applicable for BEO-III because it will ensure that the necessary additions to RAMONA5-FA are 1492 properly identified and incorporated with the introduction of new fuel types and that all physical 1493 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 1494 1495 this existing fuel development process. Through its existing regulatory processes, including 1496 inspection and review of licensing actions, the NRC staff retains appropriate oversight of vendor 1497 determinations concerning methods applications to new fuel products. Therefore, no additional

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1500 <u>Gap Conductance Sensitivity</u> 1501

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.

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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.

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1516 However, such a limitation is not necessary for BEO-III because [[1517

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1519 resulting impact on the BEO-III FoMs, will be accounted for by the BEO-III methodology.
1520 Through its existing regulatory processes, including inspection and review of licensing actions,
1521 the NRC staff retains appropriate oversight of this issue. Therefore, no limitation is necessary
1522 with regard to gap sensitivity.

1524 <u>Limitations and Conditions</u> 1525

- 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.

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1549 NRC staff relied upon as the basis for the finding of acceptability in this SE, without prior
 1550 NRC review and approval.
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- 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.
 - 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.

1568 **5.0** <u>CONCLUSIONS</u>

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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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