AREVA Report No. 51-9189034-000, *Brunswick Unit 2 Cycle 21 SLMCPR Analysis With SAFLIM3D Methodology – Operability Assessment (Nonproprietary Version)*

20004-018 (10/18/2010)

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ENGINEERING INFORMATION RECORD

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Safety Related? ☒ YES ☐ NO

Does this document contain assumptions requiring verification? ☐ YES ☒ NO

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Record of Revision

Revision No.	Pages/Sections/ Paragraphs Changed	Brief Description / Change Authorization
000	All	Initial issue of document

1.0 Purpose

Reference 1 presents results of the Brunswick Unit 2 Cycle 21 (BRK2-21) safety limit minimum critical power ratio (SLMCPR) analysis using the currently approved Reference 2 ACE/ATRIUM™ 10XM* critical power correlation. As discussed in Reference 3, a concern was identified in the calculation of the K-factor within the approved ACE/ATRIUM 10XM correlation. The K-factor methodology was modified in response to the deficiencies found in the axial averaging process. An updated correlation for use in the Brunswick SLMCPR operability assessment calculations with ATRIUM 10XM fuel is described in Reference 3.

The purpose of this report is to present results of an operability assessment for the BRK2-21 SLMCPR calculations presented in Reference 1 using the updated critical power correlation described in Reference 3 for the ATRIUM 10XM fuel. The results of this analysis are used to demonstrate the applicability of the Brunswick Unit 2 SLMCPR two-loop operation (TLO) and single-loop operation (SLO) values proposed in Reference 4 with the introduction of the Reference 1 methodology. The approach used in this operability assessment is consistent with the licensing condition proposed in Reference 4.

2.0 Methodology

The analysis presented in this document used the methodology presented in Reference 5 and the operability assessment critical power correlation presented in Reference 3 for the ATRIUM 10XM fuel. The SLMCPR is defined as the minimum value of the critical power ratio which ensures that at least 99.9% of the fuel rods in the core are expected to avoid boiling transition during normal operation or an anticipated operational occurrence (AOO). The SLMCPR is determined using a statistical analysis that employs a Monte Carlo process that perturbs key input parameters used in the calculation of MCPR. The set of uncertainties used in the statistical analysis include both fuel-related and plant-related uncertainties.

The SLMCPR analysis is performed with a power distribution that conservatively represents expected reactor operating states that could both exist at the operating limit MCPR (OLMCPR) and produce a MCPR equal to the SLMCPR during an AOO. [

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* ATRIUM is a trademark of AREVA NP.

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In the AREVA methodology, the effects of channel bow on the critical power performance are accounted for in the SLMCPR analysis. Reference 5 discusses the application of a realistic channel bow model.

3.0 Analysis

The core loading and cycle depletion from the Brunswick Unit 2 Cycle 21 (BRK2-21) fuel cycle design was used as the basis of the SLMCPR analysis. Figure 1 presents the core loading including the assembly type, the cycle the fuel was originally loaded, and the number of assemblies. The BRK2-21 core is made up of ATRIUM 10XM and ATRIUM-10 fuel. Analyses were performed [

] for the Brunswick power/flow map for MELLLA operation as shown in Figure 2. The BSP regions shown in the power/flow map are based on the methods discussed in Reference 6. The radial power distribution [

] is presented in Figure 3.

The operability assessment critical power correlation is used for the ATRIUM 10XM fuel while the SPCB critical power correlation (Reference 7) is used for the ATRIUM-10 fuel.

The fuel- and plant-related uncertainties used in the BRK2-21 SLMCPR analysis are presented in Table 1. The radial and nodal power uncertainty used in the analysis include the effects of up to 40% of the TIP channels out-of-service, up to 50% of the LPRMs out-of-service, and a 2500 effective full power hour (EFPH) LPRM calibration interval.

The BRK2-21 SLMCPR operability assessment analysis supports a TLO SLMCPR of 1.06 and an SLO SLMCPR of 1.08. Table 2 presents a summary of the analysis results including the SLMCPR and the percentage of rods expected to experience boiling transition. The percentages of the total number of fuel rods predicted to experience boiling transition in the overall Monte Carlo statistical evaluation associated with each nuclear fuel type are presented in Table 3. The results are for the [

].

4.0 Discussion of Results

Results from Reference 1 based on the currently approved ACE/ATRIUM 10XM critical power correlation (Reference 2) are presented in Table 4. They are based on the same BRK2-21 design step-through and most of the same fuel- and plant-related uncertainties. The one exception is a slightly higher additive constant uncertainty associated with the currently approved correlation for the ATRIUM 10XM fuel – [ ]. The other major difference is the application of the improved K-factor methodology described in Reference 3.

The results show that the operability assessment supports TLO and SLO SLMCPR values 0.01 less than the Reference 1 analysis. Overall, the Reference 1 results and the operability assessment results

reported herein continue to support the proposed Brunswick Unit 2 TLO SLMCPR of 1.08 and SLO SLMCPR of 1.11 presented in Reference 4.

5.0 References

1. 51-9186363-000, "Brunswick Unit 2 Cycle 21 SLMCPR Analysis With SAFLIM3D Methodology (Proprietary Version)," AREVA NP, August 2012.
2. ANP-10298PA Revision 0, *ACE/ATRIUM 10XM Critical Power Correlation*, AREVA NP, March 2010.
3. ANP-3086(P) Revision 0, *Brunswick Unit 1 and Unit 2 SLMCPR Operability Assessment Critical Power Correlation for ATRIUM 10XM Fuel - Improved K-factor Model,* AREVA NP, February 2012.
4. Letter, M.J. Annacone (PGN) to USNRC, "Brunswick Steam Electric Plant Units Nos. 1 and 2 Renewed Facility Operating License Nos. DPR-71 and DPR-62 Docket Nos. 50-325 and 50-324 Request for License Amendments – Addition of Analytical Methodology Topical Report to Technical Specification 5.6.5, "CORE OPERATING LIMITS REPORT (COLR)" and Revision to Technical Specification 2.1.1.2 Minimum Critical Power Ratio Safety Limit," BSEP 12-0031, March 2012 (NRC Accession Number ML12076A062).
5. ANP-10307PA Revision 0, *AREVA MCPR Safety Limit Methodology for Boiling Water Reactors*, AREVA NP, June 2011.
6. 0G02-0119-260, *Backup Stability Protection (BSP) for Inoperable Option III Solution,* GE Nuclear Energy, July 27, 2002.
7. EMF-2209(P)(A) Revision 3, *SPCB Critical Power Correlation*, AREVA NP, September 2009.
8. EMF-2158(P)(A) Revision 0, *Siemens Power Corporation Methodology for Boiling Water Reactors: Evaluation and Validation of CASMO-4 / MICROBURN-B2*, Siemens Power Corporation, October 1999.
9. EMF-2493(P) Revision 0, *MICROBURN-B2 Based Impact of Failed/Bypassed LPRMs and TIPs, Extended LPRM Calibration Interval, and Single Loop Operation on Measured Radial Bundle Power Uncertainty*, Siemens Power Corporation, December 2000.
10. NEDO-10958-A, *General Electric BWR Thermal Analysis Basis (GETAB): Data, Correlation and Design Application*, General Electric, January 1977.
11. NEDO-20340, *Process Computer Performance Evaluation Accuracy*, General Electric, June 1974.
12. NEDO-24344, *Brunswick Steam Electric Plant Units 1 and 2 Single-Loop Operation*, General Electric, September 1981.
13. Letter, H.D. Curet (AREVA) to H.J. Richings (NRC), "POWERPLEX Core Monitoring: Failed or Bypassed Instrumentation and Extended Calibration," HDC:96:012, May 6, 1996 (38-9043714-000).
14. 0B21-1305 Revision 1, "Core Monitoring LPRM Uncertainty and Sensitivity Decay," Progress Energy, March 2009 (NRC Accession Number ML092370285).

Table 1 Fuel- and Plant-Related Uncertainties for BRK2-21 SLMCPR Analyses

Parameter	Uncertainty	Reference
Fuel-Related Uncertainties		
[		
		]
Plant-Related Uncertainties		
Feedwater flow rate	1.8%‡	10
Feedwater temperature	0.8%‡	10
Core pressure	0.8%‡, §	11
Total core flow rate TLO SLO	 2.5% 6.0%	 10 12

* [ ]

† Values from Reference 9 are a result of the application of the methodology discussed in Reference 13 to the base uncertainties presented in Reference 8. The uncertainties presented support operation with up to 50% of LPRMs out-of-service, up to 40% of the TIP channels out-of-service, and a 2500 EFPH LPRM calibration interval. The bases of these values include a core monitoring LPRM detector uncertainty of 4.3% from Reference 14.

‡ Referenced plant uncertainties were rounded up to the nearest 0.1% before use.

§ The core pressure uncertainty is taken in Reference 11 to be a more conservative value than accepted in Reference 10; therefore, the more conservative value is used.

Table 2 BRK2-21 Results Summary for SLMCPR Analysis (Operability Assessment CPR Correlation for ATRIUM 10XM)

SLMCPR	Percentage of Rods in Boiling Transition
TLO – 1.06	0.063
SLO – 1.08	0.077

Table 3 Contribution of Total Predicted Rods in BT by Nuclear Fuel Type

Nuclear Fuel Type	Fuel Design	Burnup Status	Contribution of Total Rods Predicted To Be in BT (%)	
			TLO	SLO
30	ATRIUM-10	Twice burned	[	
31	ATRIUM-10	Twice burned		
33	ATRIUM 10XM	Once burned		
34	ATRIUM 10XM	Once burned		
35	ATRIUM 10XM	Fresh		
36	ATRIUM 10XM	Fresh		]

Table 4 BRK2-21 Results Summary for SLMCPR Analysis (Reference 2 ACE/ATRIUM 10XM CPR Correlation)

SLMCPR	Percentage of Rods in Boiling Transition
TLO – 1.07	0.085
SLO – 1.09	0.075

J: / I:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1									30	30	30	30	30	30	30	30	30	30								
2								31	30	33	33	33	33	33	33	33	33	30	30							
3					31	30	30	30	33	35	33	35	35	35	35	33	35	33	30	30	31	31				
4				31	30	30	33	33	35	35	35	35	33	33	35	35	35	35	33	33	30	30	31			
5			31	30	33	35	33	35	35	33	36	34	36	36	34	36	33	35	35	33	35	33	30	31		
6			31	34	35	33	35	35	33	36	34	36	34	34	36	34	36	34	35	35	33	35	30	31		
7			30	30	33	35	36	34	36	34	36	34	36	36	34	36	34	36	34	36	35	33	33	30		
8		30	30	33	35	35	34	36	34	36	34	36	34	34	36	34	36	34	36	34	35	35	33	30	31	
9	31	30	33	35	35	34	36	34	36	34	36	34	36	36	34	36	34	36	34	36	34	35	35	33	30	30
10	30	33	35	35	33	36	34	36	34	36	34	36	34	34	36	34	36	34	36	34	36	33	35	35	33	30
11	30	33	33	35	36	34	36	34	36	34	36	34	36	36	34	36	34	36	34	36	34	36	35	33	33	30
12	30	33	35	35	34	36	34	36	34	36	34	36	34	34	36	34	36	34	36	34	36	34	35	35	33	30
13	30	33	35	33	36	34	36	34	36	34	36	34	36	34	34	36	34	36	34	36	34	36	33	35	33	30
14	30	33	35	33	36	34	36	34	36	34	36	34	34	36	34	36	34	36	34	36	34	36	33	35	33	30
15	30	33	35	35	34	36	34	36	34	36	34	36	34	34	36	34	36	34	36	34	36	34	35	35	33	30
16	30	33	33	35	36	34	36	34	36	34	36	34	36	36	34	36	34	36	34	36	34	36	35	33	33	30
17	30	33	35	35	33	36	34	36	34	36	34	36	34	34	36	34	36	34	36	34	36	33	35	35	33	30
18	30	30	33	35	35	34	36	34	36	34	36	34	36	36	34	36	34	36	34	36	34	35	35	33	30	30
19		31	30	33	35	35	34	36	34	36	34	36	34	34	36	34	36	34	36	34	35	35	33	30	31	
20			30	33	33	35	36	34	36	34	36	34	36	36	34	36	34	36	34	36	35	33	33	30		
21			31	30	35	33	35	35	33	36	34	36	34	34	36	34	36	33	35	35	33	35	30	31		
22			31	30	33	35	33	35	35	33	36	34	36	36	34	36	33	35	35	33	35	33	30	31		
23				31	30	30	30	33	35	35	35	35	33	33	35	35	35	35	33	30	30	30	31			
24					31	31	30	30	33	35	33	35	35	35	35	33	35	33	30	30	31	31				
25								30	30	33	33	33	33	33	33	33	33	30	31							
26									31	30	30	30	30	30	30	30	30	30								

Nuclear Fuel Type	Fuel Description	Cycle Loaded	Number of Assemblies
30	ATRIUM-10	19	84
31	ATRIUM-10	19	26
33	ATRIUM 10XM	20	96
34	ATRIUM 10XM	20	128
35	ATRIUM 10XM	21	96
36	ATRIUM 10XM	21	130

Figure 1 Brunswick Unit 2 Cycle 21
Core Loading Map

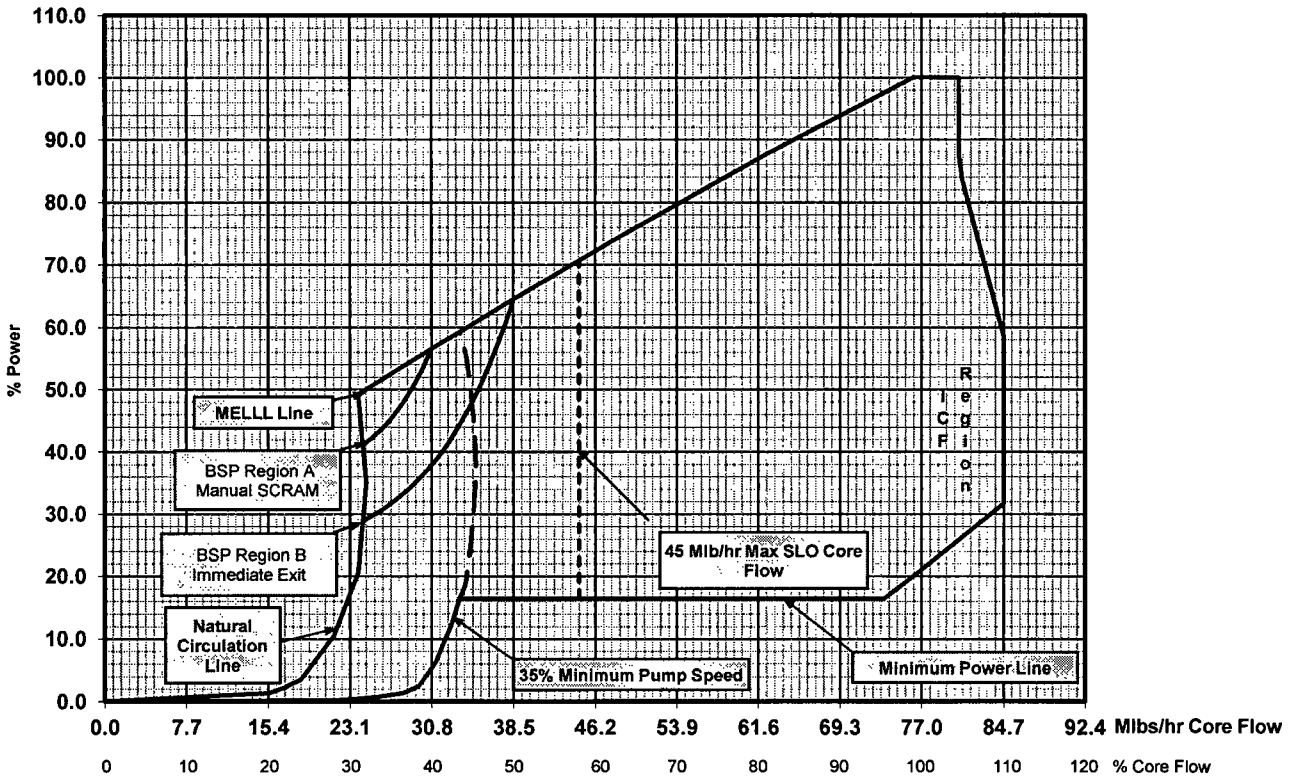

Figure 2 Brunswick Unit 2
Power/Flow Map With Nominal
Feedwater Temperature BSP Regions

J:	1	2	3	4	5	6	7	8	9	10	11	12	13
I:													
1									0.273	0.352	0.398	0.420	0.427
2								0.340	0.503	0.681	0.738	0.772	0.789
3					0.233	0.331	0.453	0.598	0.823	1.075	0.989	1.163	1.169
4				0.271	0.456	0.589	0.782	0.919	1.190	1.272	1.306	1.310	1.128
5			0.248	0.454	0.718	1.008	1.015	1.261	1.332	1.180	1.371	1.127	1.326
6			0.335	0.744	1.013	1.032	1.304	1.366	1.187	1.392	1.154	1.336	1.067
7			0.452	0.692	1.012	1.300	1.363	1.173	1.411	1.178	1.389	1.101	1.009
8		0.356	0.583	0.890	1.249	1.358	1.168	1.399	1.190	1.407	1.165	1.317	0.858
9	0.268	0.504	0.822	1.183	1.324	1.155	1.401	1.170	1.389	1.168	1.380	1.131	1.303
10	0.353	0.686	1.077	1.274	1.184	1.391	1.169	1.364	1.110	1.306	1.127	1.349	1.128
11	0.403	0.746	0.999	1.318	1.382	1.170	1.395	1.120	1.021	0.858	1.259	1.096	1.305
12	0.424	0.783	1.179	1.334	1.161	1.398	1.166	1.316	0.851	0.982	1.028	1.264	1.052
13	0.432	0.802	1.189	1.160	1.388	1.170	1.395	1.119	1.253	1.027	1.223	1.027	1.231
14	0.432	0.799	1.189	1.158	1.387	1.169	1.394	1.119	1.252	1.026	1.220	1.020	1.020
15	0.424	0.782	1.178	1.333	1.162	1.396	1.162	1.313	0.849	0.978	1.025	1.253	1.045
16	0.401	0.746	0.998	1.317	1.380	1.167	1.392	1.117	1.018	0.855	1.254	1.092	1.303
17	0.353	0.685	1.077	1.273	1.182	1.388	1.165	1.360	1.108	1.303	1.124	1.348	1.128
18	0.276	0.503	0.822	1.185	1.323	1.153	1.397	1.168	1.386	1.166	1.378	1.133	1.305
19		0.339	0.592	0.911	1.248	1.352	1.161	1.394	1.186	1.404	1.164	1.318	0.859
20			0.444	0.764	1.002	1.288	1.352	1.164	1.405	1.176	1.389	1.100	1.010
21			0.312	0.577	0.982	1.010	1.284	1.351	1.179	1.387	1.152	1.336	1.069
22			0.222	0.422	0.682	0.967	0.987	1.236	1.318	1.174	1.367	1.125	1.326
23				0.251	0.408	0.530	0.671	0.881	1.172	1.262	1.300	1.307	1.126
24					0.212	0.292	0.408	0.567	0.810	1.064	0.982	1.158	1.165
25								0.341	0.493	0.675	0.733	0.768	0.786
26									0.257	0.347	0.395	0.417	0.424
	1	2	3	4	5	6	7	8	9	10	11	12	13

J:	14	15	16	17	18	19	20	21	22	23	24	25	26
I:													
1	0.431	0.424	0.404	0.359	0.280								
2	0.791	0.778	0.746	0.698	0.507	0.353							
3	1.170	1.164	0.991	1.075	0.824	0.595	0.448	0.315	0.224				
4	1.131	1.309	1.303	1.267	1.183	0.913	0.772	0.578	0.427	0.255			
5	1.326	1.126	1.366	1.166	1.322	1.250	1.005	0.990	0.692	0.434	0.225		
6	1.067	1.334	1.151	1.384	1.153	1.354	1.291	1.017	0.985	0.553	0.308		
7	1.009	1.099	1.386	1.177	1.402	1.164	1.352	1.288	0.999	0.758	0.442		
8	0.858	1.315	1.163	1.401	1.184	1.391	1.159	1.350	1.245	0.896	0.581	0.335	
9	1.302	1.130	1.376	1.164	1.382	1.165	1.393	1.150	1.320	1.181	0.819	0.502	0.275
10	1.127	1.345	1.123	1.300	1.105	1.356	1.164	1.384	1.180	1.271	1.076	0.684	0.352
11	1.302	1.091	1.252	0.854	1.014	1.115	1.388	1.165	1.377	1.315	0.998	0.746	0.401
12	1.046	1.252	1.023	0.976	0.847	1.309	1.164	1.393	1.158	1.332	1.178	0.782	0.424
13	1.020	1.020	1.218	1.025	1.249	1.116	1.390	1.168	1.385	1.157	1.188	0.801	0.431
14	1.231	1.027	1.222	1.025	1.250	1.116	1.391	1.169	1.386	1.161	1.189	0.802	0.432
15	1.052	1.264	1.029	0.980	0.850	1.313	1.160	1.396	1.163	1.334	1.180	0.785	0.425
16	1.305	1.096	1.258	0.857	1.020	1.119	1.393	1.167	1.380	1.318	1.000	0.748	0.403
17	1.128	1.350	1.126	1.305	1.110	1.362	1.168	1.389	1.185	1.274	1.078	0.687	0.351
18	1.305	1.133	1.380	1.166	1.387	1.167	1.398	1.154	1.323	1.184	0.822	0.503	0.275
19	0.859	1.319	1.165	1.405	1.186	1.394	1.162	1.352	1.247	0.908	0.582	0.335	
20	1.010	1.101	1.389	1.176	1.405	1.163	1.352	1.287	0.999	0.760	0.427		
21	1.070	1.336	1.153	1.388	1.179	1.351	1.284	1.012	0.979	0.568	0.309		
22	1.326	1.127	1.368	1.171	1.318	1.237	0.988	0.968	0.682	0.420	0.223		
23	1.125	1.307	1.300	1.262	1.172	0.882	0.673	0.538	0.408	0.245			
24	1.165	1.158	0.982	1.064	0.810	0.566	0.407	0.292	0.209				
25	0.786	0.768	0.733	0.675	0.494	0.328							
26	0.423	0.416	0.395	0.348	0.269								
	14	15	16	17	18	19	20	21	22	23	24	25	26

Figure 3 Radial Power Distribution for Brunswick Unit 2 Cycle 21 SLMCPR [ ] With Operability Assessment CPR Correlation