AREVA Report No. 51-9177317-001, *Brunswick Unit 1 Cycle 19 SLMCPR Analysis With SAFLIM3D Methodology (Nonproprietary Version)*

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Brunswick Unit 1 Cycle 19 SLMCPR Analysis With SAFLIM3D Methodology (Nonproprietary Version)

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Record of Revision

Revision No.	Pages/Sections/ Paragraphs Changed	Brief Description / Change Authorization
000	All	Initial issue of document.
001	Page 7, Table 4	SAFLIM2 SLO SLMCPR changed to 1.12.

Changes are further identified by a vertical bar in the right-hand margin.

1.0 Purpose

Reference 1 presents an AREVA methodology for determining the safety limit minimum critical power ratio (SLMCPR) that was recently approved by the NRC. The methodology is an update or extension of the previously approved methodology presented in Reference 2. The SLMCPR methodology was updated to incorporate full implementation of the ACE critical power correlation (References 3 and 4), a realistic fuel channel bow model (Reference 5), and expanded coupling with the MICROBURN-B2 core simulator (Reference 6). More detailed descriptions of these improvements are discussed in Reference 1. The purpose of this report is to provide SLMCPR results for Brunswick Unit 1 Cycle 19 using the Reference 1 methodology to support a change in the list of approved methodologies in the Technical Specifications and also a change in the Technical Specification SLMCPR values for two-loop operation (TLO) and single-loop operation (SLO).

2.0 Methodology

The analysis presented in this document used the methodology presented in Reference 1. 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. [

]

In the AREVA methodology, the effects of channel bow on the critical power performance are accounted for in the SLMCPR analysis. Reference 1 discusses the application of a realistic channel bow model.

3.0 Analysis

The core loading and cycle depletion from the Brunswick Unit 1 Cycle 19 (BRK1-19) fuel cycle design report (Reference 7) 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 BRK1-19 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/map are based on the methods discussed in Reference 8. The radial power distribution [ ] is presented in Figure 3.

The ACE/ATRIUM 10XM critical power correlation (Reference 4) is used for the ATRIUM 10XM fuel while the SPCB critical power correlation (Reference 9) is used for the ATRIUM-10 fuel.

The fuel- and plant-related uncertainties used in the BRK1-19 SLMCPR analysis are presented in Table 1. The radial and nodal power uncertainties 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 BRK1-19 SLMCPR analysis supports a TLO SLMCPR of 1.07 and an SLO SLMCPR of 1.09. 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 of the SLMCPR analysis using the Reference 2 methodology based on the same BRK1-19 design step-through and the same fuel- and plant-related uncertainties† are shown in Table 4. The results show a significant decrease in both the TLO and SLO SLMCPR limits with the Reference 1 methodology. The SLMCPR differences are primarily a result of the following differences in the methodologies:

- Implementation of the realistic channel bow model
- Explicit use of the [ ] as a result of the expanded coupling with MICROBURN-B2

The improved SLMCPR results with the Reference 1 methodology are consistent with the results presented in Tables 4-1 and 4-3 of Reference 1.

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* ATRIUM is a trademark of AREVA NP.

† [ ]

5.0 References

1. ANP-10307PA Revision 0, *AREVA MCPR Safety Limit Methodology for Boiling Water Reactors*, AREVA NP, June 2011.

2. ANF-524(P)(A) Revision 2 and Supplements 1 and 2, *ANF Critical Power Methodology for Boiling Water Reactors,* Advanced Nuclear Fuels Corporation, November 1990.

3. ANP-10249PA Revision 1, *ACE/ATRIUM-10 Critical Power Correlation*, AREVA NP, September 2009.

4. ANP-10298PA Revision 0, *ACE/ATRIUM 10XM Critical Power Correlation*, AREVA NP, March 2010.

5. BAW-10247PA Revision 0, *Realistic Thermal-Mechanical Fuel Rod Methodology for Boiling Water Reactors*, AREVA NP, February 2008.

6. 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.

7. ANP-3005(P) Revision 0, *Brunswick Unit 1 Cycle 19 Fuel Cycle Design*, AREVA NP, June 2011.

8. 0G02-0119-260, *Backup Stability Protection (BSP) for Inoperable Option III Solution,* GE Nuclear Energy, July 17, 2002.

9. EMF-2209(P)(A) Revision 3, *SPCB Critical Power Correlation*, AREVA NP, September 2009.

10. EMF-2493(P), *MICROBURN-B2 Based Impact of Failed/Bypassed LPRMs and TIPs, Extended LPRM Calibration Interval, and Single Loop Operation on Measured Radial Bundle Power Uncertainty*, AREVA NP, December 2000.

11. NEDO-20340, *Process Computer Performance Evaluation Accuracy*, General Electric, June 1974.

12. NEDO-10958-A, *General Electric BWR Thermal Analysis Basis (GETAB): Data, Correlation and Design Application*, General Electric, January 1977.

13. NEDO-24344, *Brunswick Steam Electric Plant Units 1 and 2 Single-Loop Operation*, General Electric, September 1981.

14. 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).

15. 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 BRK1-19 SLMCPR Analyses

Parameter	Uncertainty	Reference
Fuel-Related Uncertainties		
[		
		]
Plant-Related Uncertainties		
Feedwater flow rate	1.8%[‡]	12
Feedwater temperature	0.8%[‡]	12
Core pressure	0.8%[‡, §]	11
Total core flow rate TLO SLO	 2.5% 6.0%	 12 13

* [ ]

† Values from Reference 10 are a result of the application of the methodology discussed in Reference 14 to the base uncertainties presented in Reference 6. The uncertainties presented support operation with up to 50% of the 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 15.

‡ 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 12; therefore, the more conservative value is used.

Table 2 BRK1-19 Results Summary for SLMCPR Analysis (Reference 1 SAFLIM3D Methodology)

SLMCPR	Percentage of Rods in Boiling Transition
TLO – 1.07	0.073
SLO – 1.09	0.083

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		
32	ATRIUM-10	Once burned		
33	ATRIUM-10	Once burned		
34	ATRIUM 10XM	Fresh		
35	ATRIUM 10XM	Fresh		]

Table 4 BRK1-19 Results Summary for SLMCPR Analysis (Reference 2 SAFLIM2 Methodology)

SLMCPR	Percentage of Rods in Boiling Transition
TLO – 1.11	0.098
SLO – 1.12	0.098

J:	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
I:																										
1									31	31	30	30	31	30	30	30	31	31								
2								30	32	32	32	32	32	32	32	32	32	32	31							
3					31	30	31	32	32	34	33	34	34	34	34	33	34	32	32	31	30	31				
4				31	31	32	32	34	34	34	34	34	33	33	34	34	34	34	34	32	32	30	31			
5			31	30	32	34	33	34	35	33	35	33	35	35	33	35	33	35	34	33	34	32	30	31		
6			30	32	34	32	34	34	33	35	33	35	33	33	35	33	35	33	34	34	32	34	32	31		
7			30	32	33	34	35	33	35	33	35	33	35	35	33	35	33	35	33	35	34	33	32	31		
8		31	32	34	34	34	33	35	33	35	33	35	33	33	35	33	35	33	35	33	34	34	34	32	31	
9	30	32	32	34	35	33	35	33	35	33	35	33	35	35	33	35	33	35	33	35	33	35	34	32	32	30
10	31	32	34	34	33	35	33	35	33	35	33	35	33	33	35	33	35	33	35	33	35	33	34	34	32	31
11	30	32	33	34	35	33	35	33	35	33	35	33	35	35	33	35	33	35	33	35	33	35	34	33	32	30
12	30	32	34	34	33	35	33	35	33	35	33	35	33	33	35	33	35	33	35	33	35	33	34	34	32	31
13	30	32	34	33	35	33	35	33	35	33	35	33	33	35	33	35	33	35	33	35	33	35	33	34	32	30
14	31	32	34	33	35	33	35	33	35	33	35	33	35	33	33	35	33	35	33	35	33	35	33	34	32	30
15	30	32	34	34	33	35	33	35	33	35	33	35	33	33	35	33	35	33	35	33	35	33	34	34	32	31
16	30	32	33	34	35	33	35	33	35	33	35	33	35	35	33	35	33	35	33	35	33	35	34	33	32	30
17	31	32	34	34	33	35	33	35	33	35	33	35	33	33	35	33	35	33	35	33	35	33	34	34	32	31
18	30	32	32	34	35	33	35	33	35	33	35	33	35	35	33	35	33	35	33	35	33	35	34	32	32	31
19		31	32	34	34	34	33	35	33	35	33	35	33	33	35	33	35	33	35	33	34	34	34	32	31	
20			30	32	33	34	35	33	35	33	35	33	35	35	33	35	33	35	33	35	34	33	32	31		
21			30	32	34	32	34	34	33	35	33	35	33	33	35	33	35	33	34	34	32	34	32	30		
22			31	31	32	34	33	34	35	33	35	33	35	35	33	35	33	35	34	33	34	32	30	31		
23				31	30	32	32	34	34	34	34	34	33	33	34	34	34	34	34	32	32	30	31			
24					31	30	31	32	32	34	33	34	34	34	34	33	34	32	32	31	30	31				
25								31	32	32	32	32	32	32	32	32	32	32	31							
26									31	31	31	30	30	31	30	30	31	30								
	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

Nuclear Fuel Type	Fuel Description	Cycle Loaded	Number of Assemblies
30	ATRIUM-10	17	38
31	ATRIUM-10	17	46
32	ATRIUM-10	18	80
33	ATRIUM-10	18	162
34	ATRIUM 10XM	19	96
35	ATRIUM 10XM	19	138

Figure 1 Brunswick Unit 1 Cycle 19
Core Loading Map

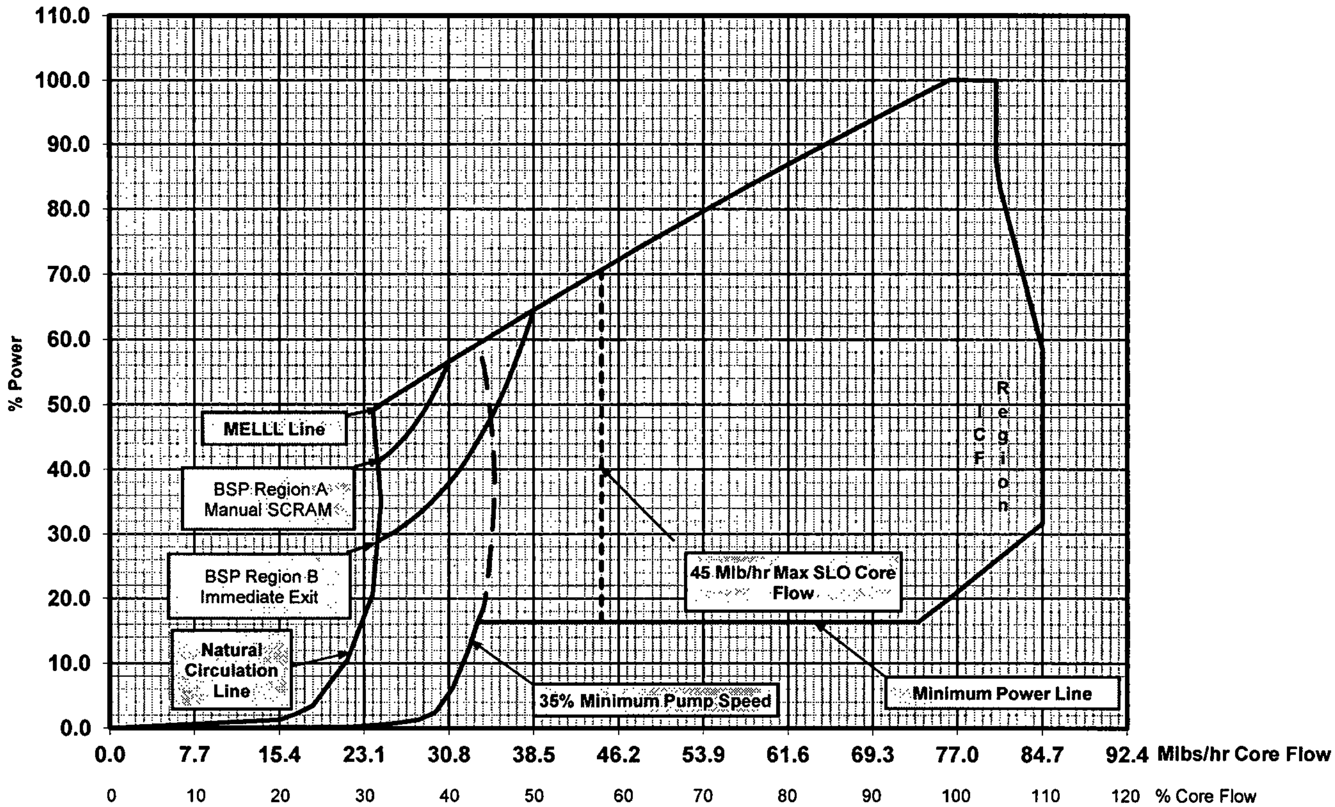

**Figure 2 Brunswick Unit 1
Power/Flow Map With Nominal
Feedwater Temperature BSP Regions**

I: \ J:	1	2	3	4	5	6	7	8	9	10	11	12	13
1									0.306	0.361	0.400	0.414	0.421
2								0.393	0.602	0.702	0.747	0.778	0.796
3					0.258	0.363	0.492	0.719	0.864	1.105	0.936	1.168	1.174
4				0.291	0.465	0.672	0.807	1.111	1.220	1.271	1.295	1.298	1.071
5			0.249	0.465	0.745	1.025	0.940	1.256	1.301	1.093	1.340	1.107	1.331
6			0.345	0.672	1.026	1.017	1.265	1.311	1.101	1.322	1.113	1.340	1.101
7			0.485	0.806	0.950	1.265	1.305	1.100	1.319	1.105	1.336	1.101	1.322
8		0.398	0.712	1.102	1.249	1.308	1.096	1.313	1.100	1.314	1.092	1.317	1.076
9	0.299	0.594	0.854	1.203	1.288	1.101	1.332	1.118	1.316	1.084	1.288	1.059	1.284
10	0.362	0.691	1.081	1.244	1.083	1.310	1.112	1.333	1.087	1.294	1.055	1.261	1.047
11	0.374	0.724	0.911	1.259	1.298	1.089	1.333	1.110	1.310	1.065	1.260	1.032	1.243
12	0.399	0.753	1.130	1.256	1.075	1.301	1.108	1.323	1.082	1.284	1.038	1.227	0.997
13	0.401	0.771	1.135	1.040	1.290	1.085	1.303	1.079	1.294	1.054	1.267	1.008	0.987
14	0.410	0.769	1.134	1.040	1.289	1.085	1.301	1.079	1.292	1.056	1.268	1.020	1.210
15	0.400	0.752	1.129	1.254	1.073	1.298	1.104	1.318	1.076	1.279	1.040	1.235	1.003
16	0.372	0.722	0.909	1.256	1.294	1.085	1.326	1.106	1.302	1.065	1.257	1.034	1.241
17	0.354	0.687	1.077	1.240	1.079	1.303	1.097	1.325	1.085	1.287	1.051	1.255	1.042
18	0.298	0.592	0.850	1.199	1.282	1.095	1.324	1.110	1.307	1.074	1.279	1.059	1.276
19		0.398	0.711	1.097	1.243	1.301	1.095	1.304	1.093	1.302	1.084	1.305	1.068
20			0.483	0.802	0.936	1.258	1.297	1.091	1.308	1.095	1.323	1.089	1.311
21			0.357	0.668	1.019	1.014	1.257	1.301	1.087	1.310	1.104	1.328	1.093
22			0.244	0.459	0.740	1.018	0.933	1.246	1.291	1.084	1.329	1.097	1.321
23				0.284	0.462	0.668	0.799	1.102	1.211	1.261	1.285	1.288	1.065
24					0.248	0.357	0.474	0.712	0.857	1.097	0.928	1.160	1.167
25								0.385	0.597	0.696	0.742	0.773	0.792
26									0.301	0.359	0.391	0.410	0.424
	1	2	3	4	5	6	7	8	9	10	11	12	13

I: \ J:	14	15	16	17	18	19	20	21	22	23	24	25	26
1	0.423	0.417	0.395	0.366	0.310								
2	0.795	0.777	0.745	0.703	0.604	0.407							
3	1.174	1.169	0.935	1.109	0.867	0.722	0.496	0.373	0.254				
4	1.070	1.300	1.299	1.276	1.227	1.118	0.813	0.678	0.468	0.291			
5	1.332	1.109	1.345	1.097	1.309	1.265	0.948	1.034	0.750	0.468	0.251		
6	1.101	1.343	1.115	1.329	1.107	1.322	1.277	1.026	1.034	0.676	0.362		
7	1.323	1.103	1.341	1.104	1.329	1.106	1.318	1.277	0.946	0.810	0.495		
8	1.076	1.321	1.101	1.323	1.109	1.327	1.107	1.323	1.262	1.112	0.718	0.401	
9	1.286	1.063	1.296	1.094	1.328	1.126	1.348	1.110	1.304	1.218	0.860	0.598	0.304
10	1.048	1.268	1.061	1.305	1.091	1.349	1.122	1.328	1.096	1.262	1.095	0.694	0.360
11	1.248	1.038	1.271	1.074	1.323	1.121	1.352	1.103	1.319	1.278	0.922	0.735	0.386
12	1.005	1.244	1.047	1.296	1.091	1.341	1.121	1.323	1.089	1.277	1.149	0.765	0.420
13	1.213	1.023	1.279	1.065	1.311	1.093	1.324	1.099	1.312	1.055	1.154	0.782	0.414
14	0.985	1.014	1.276	1.064	1.311	1.092	1.324	1.099	1.312	1.056	1.154	0.783	0.415
15	0.994	1.230	1.042	1.295	1.091	1.341	1.120	1.322	1.089	1.276	1.149	0.765	0.419
16	1.240	1.032	1.266	1.076	1.323	1.119	1.350	1.101	1.317	1.277	0.921	0.736	0.385
17	1.042	1.261	1.055	1.301	1.095	1.346	1.112	1.326	1.093	1.260	1.094	0.694	0.359
18	1.278	1.056	1.289	1.082	1.324	1.124	1.344	1.108	1.302	1.216	0.860	0.598	0.302
19	1.068	1.312	1.090	1.316	1.103	1.322	1.106	1.320	1.260	1.111	0.716	0.399	
20	1.313	1.096	1.333	1.097	1.323	1.102	1.315	1.275	0.944	0.809	0.489		
21	1.092	1.334	1.106	1.321	1.101	1.318	1.274	1.024	1.032	0.675	0.364		
22	1.322	1.101	1.336	1.089	1.304	1.262	0.956	1.032	0.749	0.465	0.252		
23	1.063	1.292	1.292	1.270	1.222	1.115	0.811	0.676	0.469	0.290			
24	1.168	1.163	0.929	1.104	0.864	0.719	0.494	0.366	0.251				
25	0.790	0.773	0.742	0.700	0.602	0.406							
26	0.422	0.415	0.401	0.364	0.312								
	14	15	16	17	18	19	20	21	22	23	24	25	26

Figure 3 Radial Power Distribution for Brunswick Unit 1 Cycle 19 SLMCPR [ ]