AREVA Report No. 51-9189033-000, *Brunswick Unit 2 Cycle 21*
SLMCPR Analysis With SAFLIM3D Methodology (Nonproprietary Version)

20004-018 (10/18/2010)

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ENGINEERING INFORMATION RECORD

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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

The safety limit minimum critical power ratio (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 purpose of this report is to provide SLMCPR analysis results for Brunswick Unit 2 Cycle 21 using the Reference 1 methodology. The results are used to demonstrate the applicability of the proposed Brunswick Unit 2 SLMCPR two-loop operation (TLO) and single-loop operation (SLO) values proposed in Reference 2 with the introduction of the Reference 1 methodology.

2.0 Methodology

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

* ATRIUM is a trademark of AREVA NP.

[ ] 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 3. 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 5) 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 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 BRK2-21 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 Brunswick Unit 2 Cycle 20 (BRK2-20) SLMCPR analysis using the Reference 1 methodology are shown in Table 4. The BRK2-20 results support a TLO SLMCPR of 1.06 and an SLO SLMCPR of 1.08, 0.01 lower than the BRK2-21 results. In the AREVA methodology, the SLMCPR is iteratively increased by integer multiples of 0.01 until the percentage of rods in boiling transition is less than 0.1%. As a result, an increase of just over 0.01% to the number of rods in boiling transition calculated in the TLO BRK2-20 analysis (approximately 5 rods) would result in an increase of 0.01 in the SLMCPR result. An increase of 0.01 results in a decrease in the number of rods predicted to experience boiling transition. The differences in the BRK2-20 and BRK2-21 SLMCPR results are consistent with expected cycle-to-cycle variations.

The BRK2-21 results continue to support the proposed Brunswick Unit 2 TLO SLMCPR of 1.08 and SLO SLMCPR of 1.11 presented in Reference 2.

5.0 References

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

2. 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).

3. 0G02-0119-260, *Backup Stability Protection (BSP) for Inoperable Option III Solution*, GE Nuclear Energy, July 17, 2002.

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

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

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. 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.

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

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

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

11. 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).

12. 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%‡	8
Feedwater temperature	0.8%‡	8
Core pressure	0.8%‡, §	9
Total core flow rate TLO SLO	 2.5% 6.0%	 8 10

* [ ]

† Values from Reference 7 are a result of the application of the methodology discussed in Reference 11 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 12.

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

§ The core pressure uncertainty is taken in Reference 9 to be a more conservative value than accepted in Reference 8; therefore, the more conservative value is used.

Table 2 BRK2-21 Results Summary for SAFLIM3D SLMCPR Analysis

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

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 BRK2-20 Results Summary for SAFLIM3D SLMCPR Analysis

SLMCPR	Percentage of Rods in Boiling Transition
TLO – 1.06	0.090
SLO – 1.08	0.088

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								
	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	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

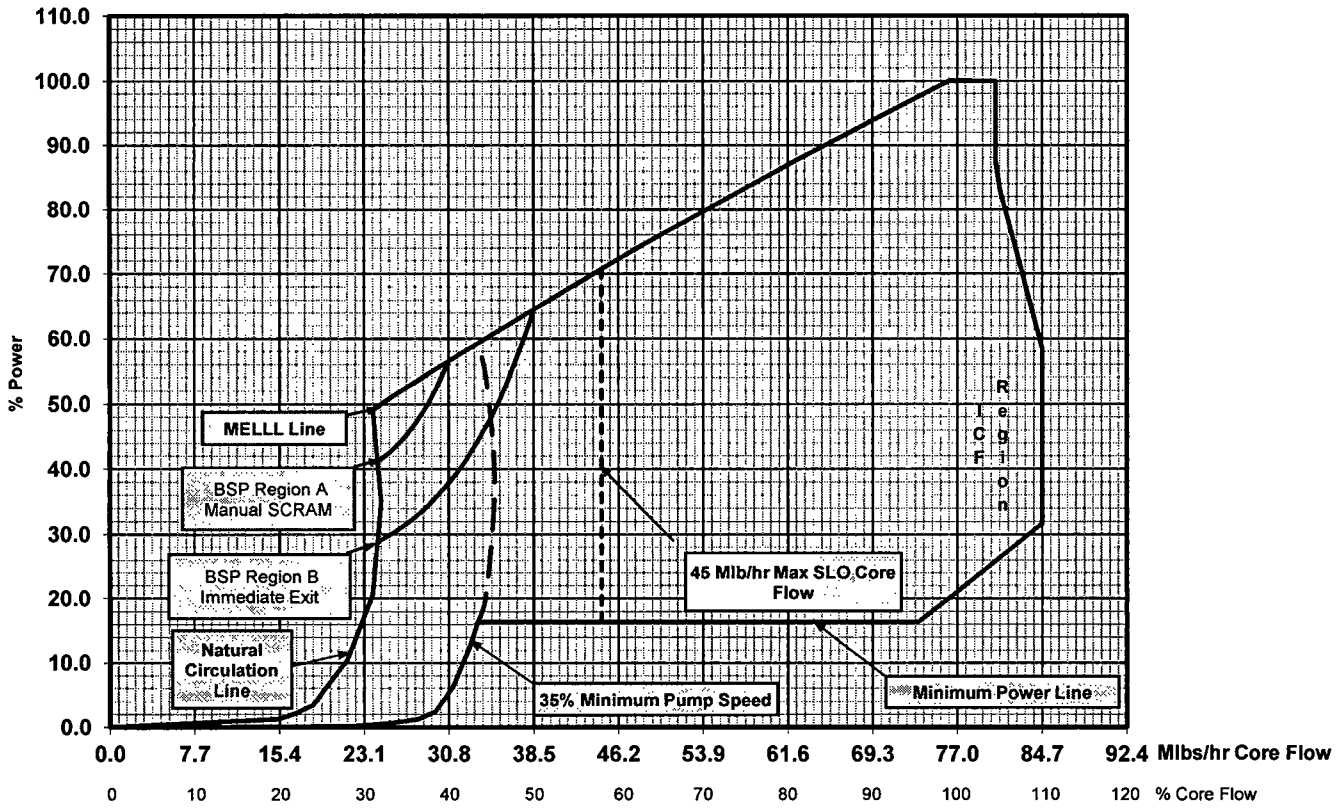

Figure 2 Brunswick Unit 2
Power/Flow Map With Nominal
Feedwater Temperature BSP Regions

J: I	1	2	3	4	5	6	7	8	9	10	11	12	13
1									0.272	0.350	0.397	0.418	0.425
2								0.338	0.500	0.678	0.735	0.768	0.786
3					0.232	0.329	0.451	0.595	0.818	1.070	0.985	1.159	1.165
4				0.269	0.453	0.586	0.777	0.913	1.184	1.266	1.300	1.305	1.124
5			0.247	0.451	0.714	1.003	1.009	1.254	1.324	1.174	1.365	1.124	1.324
6			0.333	0.739	1.008	1.025	1.296	1.357	1.180	1.385	1.151	1.336	1.073
7			0.449	0.688	1.006	1.292	1.355	1.167	1.403	1.175	1.388	1.107	1.044
8		0.354	0.580	0.885	1.241	1.350	1.162	1.392	1.186	1.404	1.166	1.326	0.888
9	0.267	0.502	0.817	1.176	1.316	1.148	1.394	1.167	1.389	1.170	1.384	1.138	1.315
10	0.351	0.682	1.071	1.266	1.176	1.383	1.166	1.365	1.118	1.317	1.135	1.356	1.134
11	0.400	0.742	0.992	1.309	1.373	1.165	1.393	1.128	1.060	0.892	1.273	1.103	1.310
12	0.422	0.778	1.172	1.325	1.154	1.392	1.166	1.327	0.885	1.024	1.042	1.273	1.058
13	0.429	0.796	1.181	1.152	1.379	1.166	1.394	1.127	1.272	1.045	1.238	1.035	1.237
14	0.429	0.794	1.181	1.151	1.378	1.165	1.394	1.127	1.271	1.044	1.235	1.029	1.026
15	0.422	0.777	1.171	1.324	1.155	1.390	1.162	1.324	0.884	1.021	1.039	1.262	1.052
16	0.399	0.741	0.991	1.308	1.371	1.162	1.390	1.125	1.057	0.890	1.269	1.100	1.309
17	0.351	0.680	1.071	1.266	1.175	1.380	1.162	1.362	1.117	1.315	1.133	1.356	1.135
18	0.275	0.500	0.817	1.178	1.315	1.146	1.390	1.166	1.386	1.169	1.384	1.141	1.318
19		0.336	0.589	0.905	1.241	1.345	1.156	1.388	1.184	1.403	1.167	1.328	0.891
20			0.441	0.759	0.996	1.281	1.345	1.159	1.399	1.173	1.388	1.108	1.046
21			0.310	0.574	0.977	1.004	1.277	1.344	1.174	1.382	1.151	1.338	1.076
22			0.220	0.420	0.678	0.963	0.982	1.231	1.312	1.169	1.362	1.124	1.325
23				0.250	0.406	0.528	0.668	0.877	1.168	1.257	1.296	1.303	1.124
24					0.211	0.291	0.406	0.565	0.807	1.061	0.979	1.155	1.162
25								0.339	0.492	0.672	0.731	0.766	0.784
26									0.256	0.347	0.394	0.416	0.424

J: I	14	15	16	17	18	19	20	21	22	23	24	25	26
1	0.429	0.422	0.402	0.357	0.279								
2	0.788	0.774	0.742	0.694	0.504	0.352							
3	1.165	1.160	0.986	1.071	0.819	0.592	0.446	0.313	0.223				
4	1.127	1.304	1.297	1.260	1.177	0.908	0.767	0.575	0.425	0.254			
5	1.323	1.123	1.360	1.160	1.314	1.242	0.998	0.984	0.687	0.432	0.224		
6	1.073	1.334	1.148	1.377	1.146	1.345	1.283	1.010	0.979	0.550	0.306		
7	1.043	1.106	1.384	1.173	1.395	1.158	1.343	1.280	0.993	0.753	0.439		
8	0.889	1.324	1.165	1.398	1.181	1.383	1.153	1.341	1.236	0.890	0.577	0.333	
9	1.314	1.137	1.380	1.166	1.381	1.162	1.385	1.143	1.311	1.173	0.814	0.499	0.274
10	1.133	1.352	1.131	1.311	1.113	1.357	1.160	1.376	1.172	1.262	1.069	0.680	0.350
11	1.307	1.098	1.266	0.888	1.053	1.121	1.385	1.159	1.367	1.306	0.991	0.740	0.398
12	1.052	1.260	1.038	1.018	0.881	1.319	1.163	1.386	1.151	1.322	1.170	0.777	0.421
13	1.026	1.028	1.233	1.042	1.267	1.123	1.389	1.163	1.375	1.149	1.181	0.796	0.429
14	1.237	1.035	1.236	1.043	1.269	1.123	1.390	1.164	1.376	1.153	1.181	0.796	0.430
15	1.058	1.273	1.044	1.023	0.885	1.324	1.160	1.389	1.156	1.325	1.172	0.779	0.422
16	1.312	1.104	1.273	0.892	1.059	1.127	1.391	1.162	1.371	1.309	0.994	0.743	0.400
17	1.136	1.358	1.135	1.317	1.119	1.364	1.165	1.381	1.177	1.266	1.072	0.682	0.349
18	1.318	1.141	1.386	1.169	1.387	1.164	1.391	1.147	1.315	1.177	0.817	0.500	0.274
19	0.890	1.329	1.168	1.404	1.184	1.388	1.157	1.344	1.239	0.902	0.579	0.333	
20	1.047	1.109	1.389	1.174	1.399	1.158	1.345	1.280	0.993	0.755	0.425		
21	1.077	1.339	1.151	1.382	1.173	1.344	1.278	1.006	0.975	0.565	0.307		
22	1.326	1.126	1.363	1.167	1.312	1.231	0.983	0.964	0.678	0.418	0.221		
23	1.124	1.304	1.296	1.258	1.168	0.878	0.670	0.536	0.406	0.243			
24	1.162	1.155	0.979	1.061	0.807	0.564	0.406	0.291	0.208				
25	0.784	0.766	0.731	0.673	0.493	0.327							
26	0.423	0.416	0.395	0.347	0.268								

Figure 3 Radial Power Distribution for Brunswick Unit 2 Cycle 21 SLMCPR [ ]