ATTACHMENT 33

FS1-0019630, Browns Ferry Unit 3 Cycle 19 MCPR Safety Limit Analysis With SAFLIM3D Methodology (Non-Proprietary)

IDENTIFICATION	REVISION
FS1-0019630	1.0

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Browns Ferry Unit 3 Cycle 19 MCPR Safety Limit Analysis With SAFLIM3D Methodology

ADDITIONAL INFORMATION:
BFE3 Cycle 19

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Role	Name	Date (YYYY/MM/DD)	Organization
Writer	WANG Peng	2015/03/25 00:00:23	AREVA Inc.
Writer	MOOSE James	2015/03/24 23:43:23	AREVA Inc.
Reviewer	TYLINSKI Scott	2015/03/25 00:27:59	AREVA Inc.
Reviewer	TOUVANNAS George	2015/03/25 00:14:25	AREVA Inc.
Approver	MEGINNIS Alan	2015/03/25 16:24:29	AREVA Inc.
Approver	SCHNEPP Robert	2015/03/25 01:12:43	AREVA Inc.

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REVISIONS

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1.0	See 1st page release date	Initial issue. This is the non-proprietary version of FS1-0019629.

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Peng WANG Engineer	W	N/A– Approval of document in electronic workflow constitutes acceptance.	N/A	All except Figure 1, Figures 5-9	
James MOOSE Engineer	W	N/A– Approval of document in electronic workflow constitutes acceptance.	N/A	Figure 1, Figures 5-9	
Scott TYLINSKI, Supervisor Engineer	R	N/A– Approval of document in electronic workflow constitutes acceptance.	N/A	All except Figure 1, Figures 5-9	B
George TOUVANNAS Engineer	R	N/A– Approval of document in electronic workflow constitutes acceptance.	N/A	Figure 1, Figures 5-9	B

1. PURPOSE

Reference 1 presents an AREVA methodology for determining the safety limit minimum critical power ratio (SLMCPR) that was 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 9), a realistic fuel channel bow model (Reference 4), and expanded coupling with the MICROBURN-B2 core simulator (Reference 5). More detailed descriptions of these improvements are discussed in Reference 1. The purpose of this report is to provide SLMCPR results for Browns Ferry Unit 3 Cycle 19 using the Reference 1 methodology to support extended power uprate (EPU) at Browns Ferry Units for two-loop operation (TLO) and single-loop operation (SLO).

2. 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. [

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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 the realistic channel bow model found in Reference 4.

3. ANALYSIS

The final core design and step-through, developed by AREVA to meet the operating requirements specified by TVA (Reference 10), was used in the BFE3-19 MCPR safety limit analysis. The BFE3-19 design supports licensed rated power of 3,952 MWt and operation to licensing end of cycle (EOC) cycle exposure of approximately 20,238.3 MWd/MTU. The design includes extensions for final feedwater temperature reduction (FFTR) and coastdown. Figure 1 presents the core loading, the cycle the fuel was originally loaded, and the number of assemblies. The BFE3-19 core is made up of ATRIUM™ 10XM* and ATRIUM-10 fuel. Analyses were performed [ ] for the Browns Ferry power/flow map for MELLLA operation as shown in Figure 2. The radial power distribution [ ] is presented in Figure 3 and Figure 4.

The calculated fast fluence gradients for the BFE3-19 core design have been compared to the upper and lower bounds of the channel bow database. As shown in Figure 5, there are [ ] the upper/lower bound of the channel bow database. The channel bow model uncertainty for the assemblies that experience fluence gradients outside the bounds of the measurement database was augmented with the same approach as demonstrated in the Response to SNPB RAI-6 in Reference 8.

The ACE/ATRIUM 10XM critical power correlation (References 3 and 9) is used for the ATRIUM 10XM fuel while the SPCB critical power correlation (Reference 6) is used for ATRIUM-10. The fuel- and plant-related uncertainties used in the BFE3-19 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.

[

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* ATRIUM is a trademark of AREVA Inc.

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The BFE3-19 SLMCPR analysis supports a TLO SLMCPR of 1.05 and an SLO SLMCPR of 1.06. 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 [

]. The BFE3-19 fuel design is presented in Figures 7 through 9.

4. DISCUSSION OF RESULTS

Compared to the TLO and SLO SLMCPR limits at the current licensed thermal power (105% OLTP) , results show a small increase in both the TLO and SLO SLMCPR limits. The SLMCPR differences are a direct result of extended power uprate. To maintain the same design margin, power distributions from the design step-through at EPU power are flatter relative to power distributions at the 105% OLTP thermal power and flatter radial power profile is more likely to produce rods in boiling transition.

5. 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-10298PA Revision 0, *ACE/ATRIUM 10XM Critical Power Correlation*, AREVA NP, March 2010.

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

5. 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.

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

7. Letter, H. Donald Curet (AREVA) to H.J. Richings (USNRC), "POWERPLEX® Core Monitoring: Failed or Bypassed Instrumentation and Extended Calibration," HDC:96:012, May 6, 1996. (38-9043714-000).

8. ANP-3248(P) Revision 1, "AREVA RAI Response for Browns Ferry ATRIUM 10XM Fuel Transition", September 2013.

9. ANP-3140(P) Revision 0, "Browns Ferry Units 1, 2, and 3 Improved K-factor Model for ACE/ATRIUM 10XM Critical Power Correlation," AREVA NP, August 2012.

10. ANP-3372P Revision 0, "Browns Ferry Unit 3 Cycle 19 EPU (120% OLTP) LAR Reference Fuel Cycle Design," AREVA, December 2014.

Table 1 Fuel- and Plant-Related Uncertainties MCPR Safety Limit Analyses

Parameter	Standard Deviation
Fuel-Related Uncertainties	
[	
	]
Plant-Related Uncertainties	
Feedwater flow rate	1.8%
Feedwater temperature	0.8%
Core pressure	0.7%
Total core flow rate TLO SLO	 2.5% 6.0%

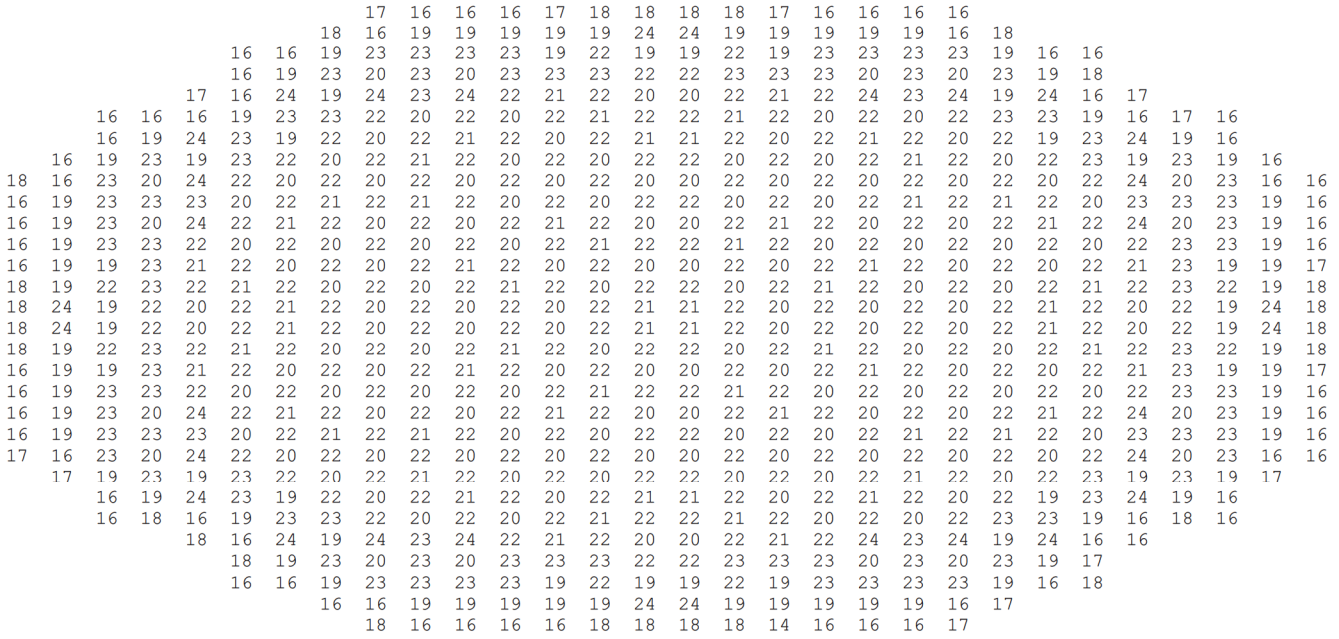
* [ ]

Table 2 Results Summary for MCPR Safety Limit Analysis

SLMCPR	Percentage of Rods in Boiling Transition
TLO – 1.05	0.0820
SLO – 1.06	0.0978

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 [ ]
14	ATRIUM-10	Twice burned	[	
16	ATRIUM-10	Twice burned		
17	ATRIUM-10	Twice burned		
18	ATRIUM-10	Twice burned		
19	ATRIUM 10XM	Once burned		
20	ATRIUM 10XM	Once burned		
21	ATRIUM 10XM	Once burned		
22	ATRIUM 10XM	Fresh		
23	ATRIUM 10XM	Fresh		
24	ATRIUM 10XM	Fresh		]



Nuclear Fuel Type	Fuel Description	Cycle Loaded	Number of Assemblies
14	ATRIUM-10	16	1*
16	ATRIUM-10	17	67
17	ATRIUM-10	17	14
18	ATRIUM-10	17	26
19	ATRIUM 10XM	18	88
20	ATRIUM 10XM	18	152
21	ATRIUM 10XM	18	64
22	ATRIUM 10XM	19	224
23	ATRIUM 10XM	19	96
24	ATRIUM 10XM	19	32

Figure 1 Browns Ferry Unit 3 Cycle 19 Core Loading Map

* This fuel assembly is a reinsert that has been withheld from plant operation one cycle for inspection purposes.

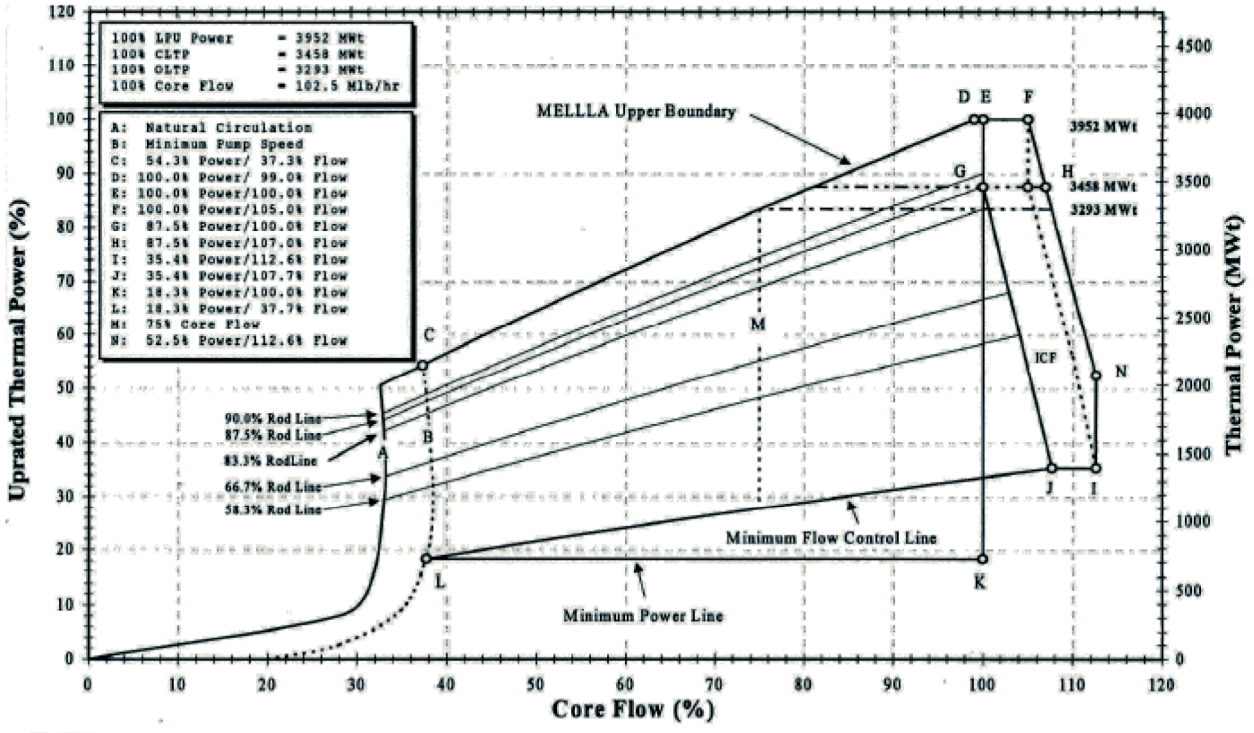


Figure 2 Browns Ferry Power / Flow Map

								0.249	0.314	0.360	0.376	0.385	0.410	0.437
							0.344	0.477	0.692	0.755	0.751	0.758	0.773	0.872
						0.224	0.383	0.657	0.900	1.018	1.085	1.109	0.999	1.099	0.965
						0.379	0.688	0.970	0.981	1.211	1.088	1.270	1.259	1.223	1.174
					0.382	0.596	1.002	1.015	1.270	1.330	1.359	1.350	1.112	1.255	0.896
			0.225	0.380	0.593	0.880	1.163	1.279	1.340	1.172	1.388	1.173	1.346	1.086	1.055
			0.389	0.691	1.004	1.164	1.124	1.338	1.178	1.376	1.161	1.370	1.170	1.337	1.105
		0.331	0.658	0.972	1.017	1.281	1.340	1.182	1.372	1.143	1.324	1.139	1.347	1.177	1.363
	0.258	0.476	0.900	0.983	1.273	1.344	1.189	1.381	1.172	1.314	0.944	1.086	1.124	1.358	1.188
	0.314	0.694	1.020	1.214	1.332	1.172	1.383	1.171	1.355	1.082	1.069	0.937	1.281	1.137	1.346
	0.358	0.759	1.089	1.090	1.361	1.379	1.152	1.356	1.150	1.289	1.069	1.224	1.057	1.278	1.112
	0.378	0.758	1.118	1.277	1.345	1.145	1.301	1.107	1.282	1.086	1.192	1.002	1.192	1.004	1.157
	0.389	0.770	1.014	1.279	1.113	1.281	0.912	1.042	1.045	1.182	0.778	0.883	0.949	1.082	0.705
	0.422	0.793	1.136	1.273	1.303	1.070	1.035	0.883	1.188	0.988	0.880	0.733	1.058	0.898	0.759
	0.451	0.903	1.007	1.261	1.112	1.267	1.028	1.196	1.023	1.163	0.955	1.061	0.928	1.036	0.842
	0.452	0.904	1.008	1.262	1.113	1.267	1.028	1.195	1.023	1.163	0.955	1.061	0.929	1.035	0.841
	0.421	0.797	1.137	1.273	1.303	1.071	1.035	0.882	1.187	0.988	0.880	0.734	1.057	0.899	0.758
	0.389	0.771	1.018	1.280	1.113	1.280	0.911	1.040	1.044	1.181	0.779	0.884	0.951	1.082	0.705
	0.380	0.759	1.119	1.277	1.344	1.145	1.298	1.105	1.278	1.087	1.191	1.001	1.191	1.004	1.155
	0.359	0.761	1.090	1.090	1.360	1.377	1.151	1.351	1.134	1.286	1.067	1.222	1.057	1.276	1.110
	0.314	0.695	1.020	1.213	1.330	1.171	1.381	1.170	1.351	1.082	1.068	0.936	1.279	1.137	1.343
	0.253	0.478	0.901	0.983	1.272	1.342	1.189	1.378	1.172	1.313	0.956	1.086	1.123	1.356	1.186
		0.334	0.658	0.972	1.018	1.280	1.338	1.180	1.370	1.143	1.324	1.140	1.345	1.176	1.359
			0.384	0.692	1.004	1.163	1.125	1.336	1.177	1.374	1.160	1.368	1.169	1.334	1.103
			0.225	0.386	0.596	0.880	1.162	1.276	1.337	1.170	1.384	1.171	1.342	1.083	1.051
					0.388	0.592	1.001	1.013	1.267	1.326	1.355	1.346	1.110	1.251	0.893
						0.384	0.687	0.969	0.979	1.208	1.085	1.266	1.255	1.219	1.170
						0.223	0.385	0.656	0.898	1.016	1.083	1.106	0.995	1.095	0.962
								0.331	0.475	0.692	0.755	0.750	0.755	0.769	0.867
									0.258	0.314	0.360	0.375	0.379	0.407	0.432

0.435	0.409	0.385	0.377	0.361	0.315	0.256								
0.872	0.773	0.758	0.753	0.757	0.694	0.478	0.344							
0.966	1.099	0.999	1.110	1.087	1.020	0.902	0.659	0.385	0.223					
1.174	1.224	1.260	1.271	1.090	1.213	0.983	0.972	0.689	0.383					
0.897	1.256	1.114	1.352	1.361	1.332	1.272	1.017	1.003	0.593	0.375				
1.056	1.087	1.348	1.176	1.390	1.174	1.342	1.281	1.165	0.881	0.595	0.377	0.222		
1.106	1.339	1.173	1.373	1.164	1.379	1.181	1.340	1.128	1.166	1.005	0.693	0.384		
1.363	1.179	1.350	1.144	1.329	1.147	1.375	1.184	1.343	1.284	1.021	0.973	0.659	0.332	
1.189	1.360	1.127	1.090	0.960	1.318	1.176	1.383	1.193	1.346	1.275	0.986	0.902	0.478	0.257
1.347	1.139	1.283	0.940	1.073	1.085	1.356	1.174	1.386	1.174	1.334	1.217	1.023	0.696	0.317
1.112	1.280	1.060	1.227	1.070	1.291	1.138	1.356	1.155	1.381	1.364	1.093	1.093	0.762	0.360
1.158	1.006	1.194	1.004	1.195	1.090	1.282	1.108	1.303	1.148	1.348	1.281	1.122	0.761	0.381
0.706	1.084	0.953	0.886	0.781	1.185	1.048	1.044	0.914	1.284	1.117	1.283	1.020	0.773	0.394
0.759	0.900	1.059	0.736	0.883	0.991	1.191	0.885	1.039	1.074	1.307	1.277	1.140	0.798	0.422
0.842	1.037	0.931	1.062	0.957	1.166	1.026	1.199	1.031	1.271	1.116	1.265	1.010	0.906	0.452
0.842	1.036	0.929	1.062	0.957	1.166	1.026	1.199	1.031	1.270	1.115	1.265	1.009	0.905	0.450
0.758	0.899	1.058	0.735	0.882	0.990	1.190	0.885	1.038	1.073	1.306	1.276	1.138	0.794	0.422
0.704	1.082	0.950	0.885	0.779	1.184	1.047	1.044	0.914	1.284	1.115	1.282	1.014	0.771	0.393
1.155	1.003	1.191	1.002	1.192	1.086	1.283	1.108	1.302	1.147	1.347	1.279	1.120	0.759	0.380
1.110	1.276	1.056	1.223	1.067	1.289	1.149	1.356	1.153	1.380	1.363	1.091	1.091	0.760	0.359
1.343	1.136	1.278	0.934	1.068	1.082	1.355	1.171	1.384	1.173	1.333	1.216	1.021	0.695	0.315
1.186	1.355	1.122	1.084	0.942	1.313	1.172	1.381	1.191	1.345	1.274	0.984	0.901	0.477	0.251
1.359	1.175	1.344	1.138	1.322	1.141	1.371	1.182	1.340	1.282	1.018	0.972	0.658	0.333	
1.102	1.333	1.167	1.367	1.159	1.374	1.178	1.337	1.122	1.164	1.003	0.690	0.384		
1.051	1.082	1.342	1.171	1.385	1.170	1.338	1.277	1.161	0.879	0.592	0.386	0.225		
0.892	1.251	1.109	1.347	1.357	1.328	1.268	1.012	1.000	0.591	0.383				
1.169	1.219	1.255	1.267	1.085	1.209	0.980	0.968	0.685	0.376					
0.961	1.095	0.992	1.105	1.082	1.015	0.897	0.655	0.383	0.230					
0.867	0.768	0.756	0.749	0.753	0.689	0.473	0.332							
0.431	0.408	0.398	0.375	0.358	0.311	0.247								

Figure 3 Radial Power Distribution Map for Browns Ferry Unit 3 Cycle 19

SLMCPR [ ]

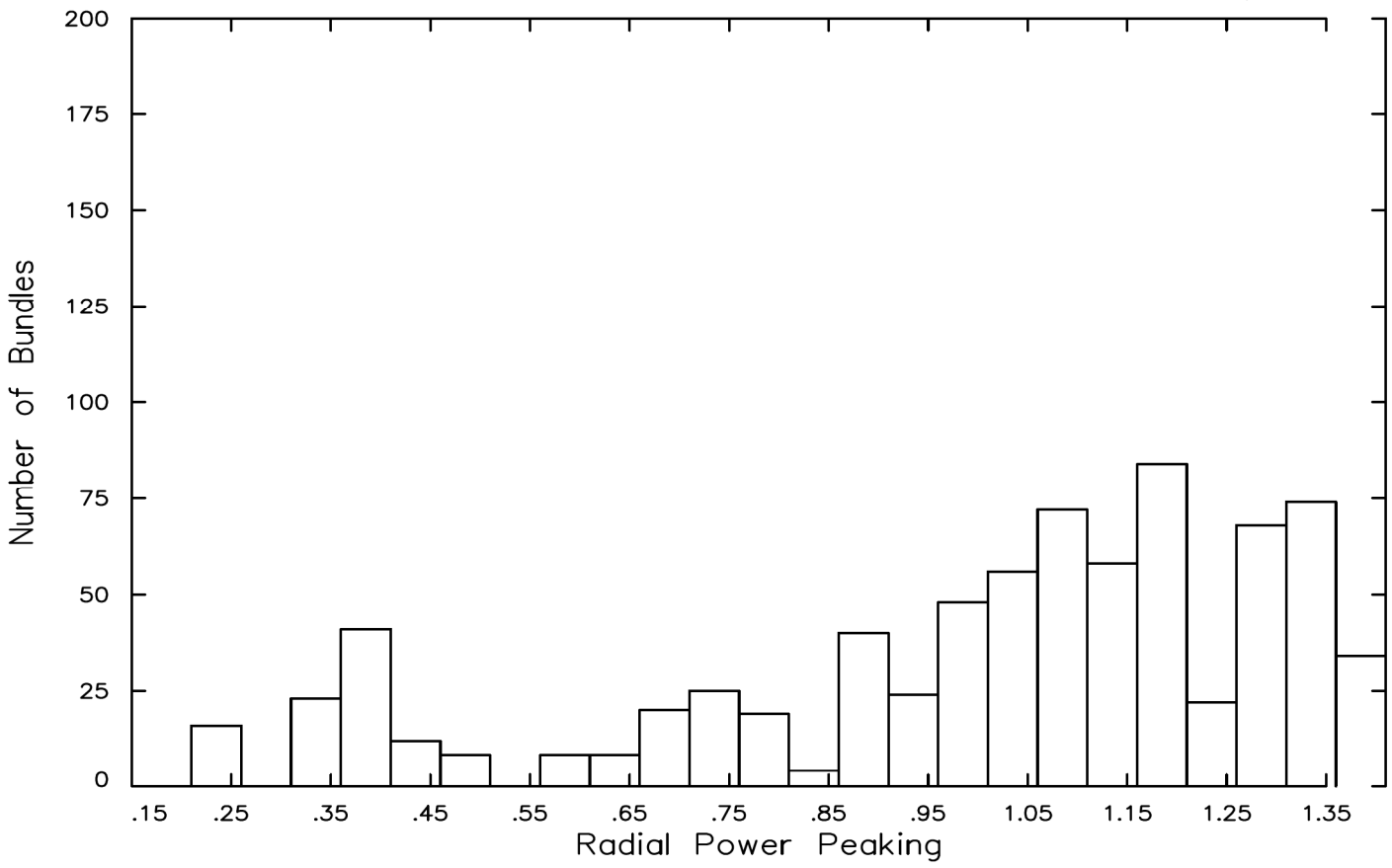


Figure 4 Radial Power Distribution for TLO/SLO Limiting Exposure of [ ]

Figure 5 Channel Fluence Gradient Distribution for Browns Ferry Unit 3 Cycle 19

Figure 6 Browns Ferry Unit 3 Cycle 19 Reference Full Core Loading Pattern

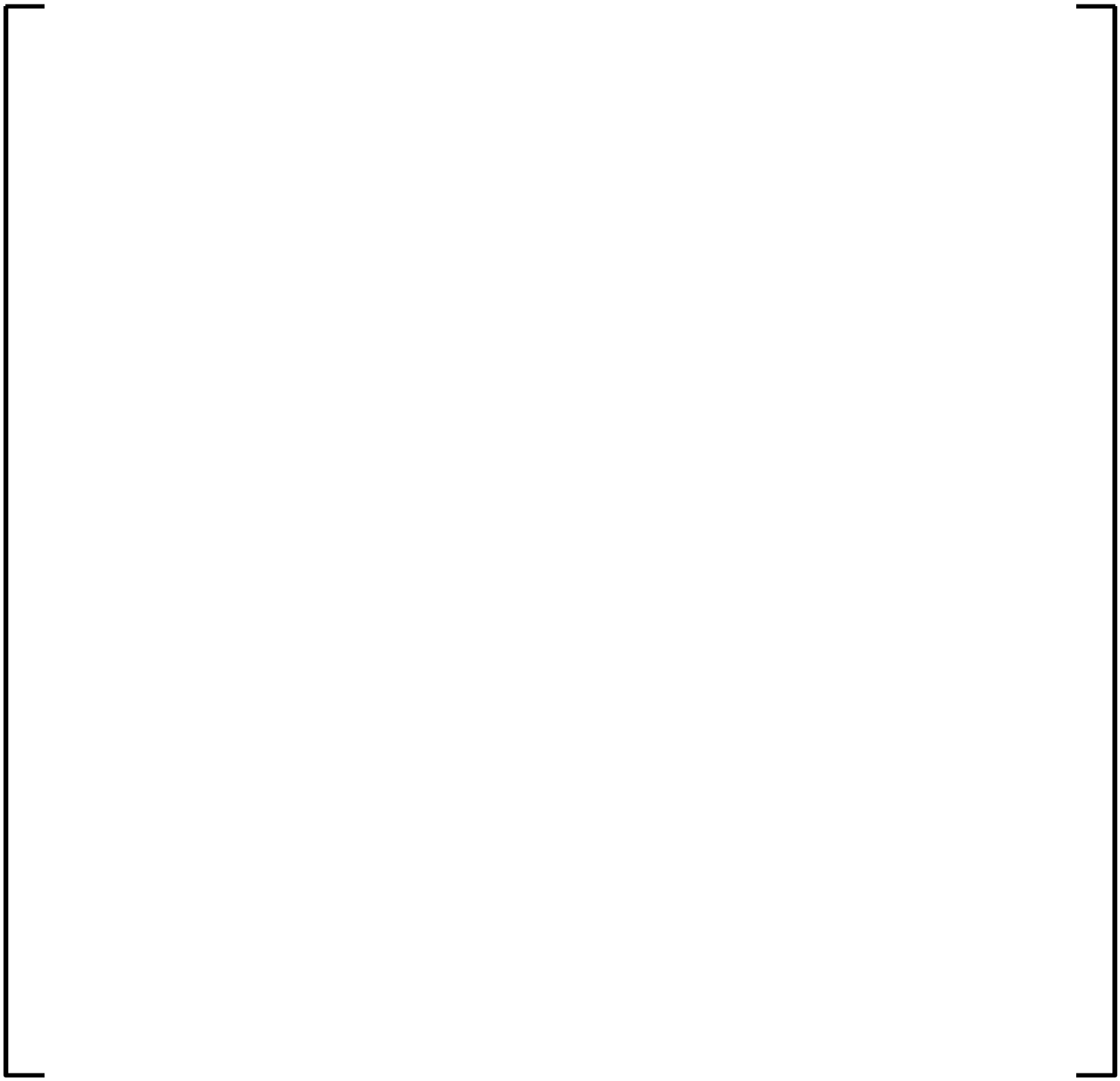


Figure 7 [

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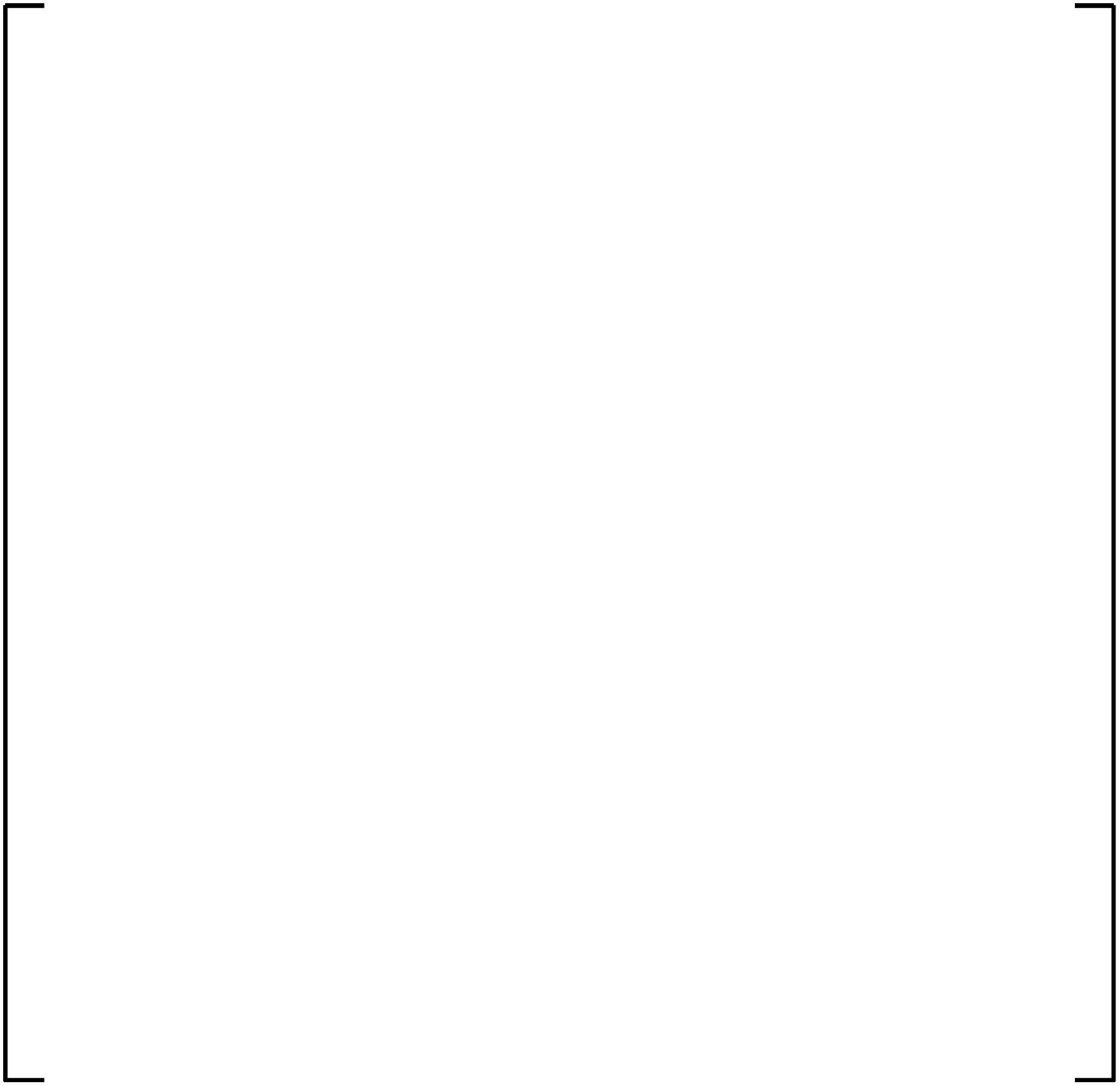

Figure 8 [

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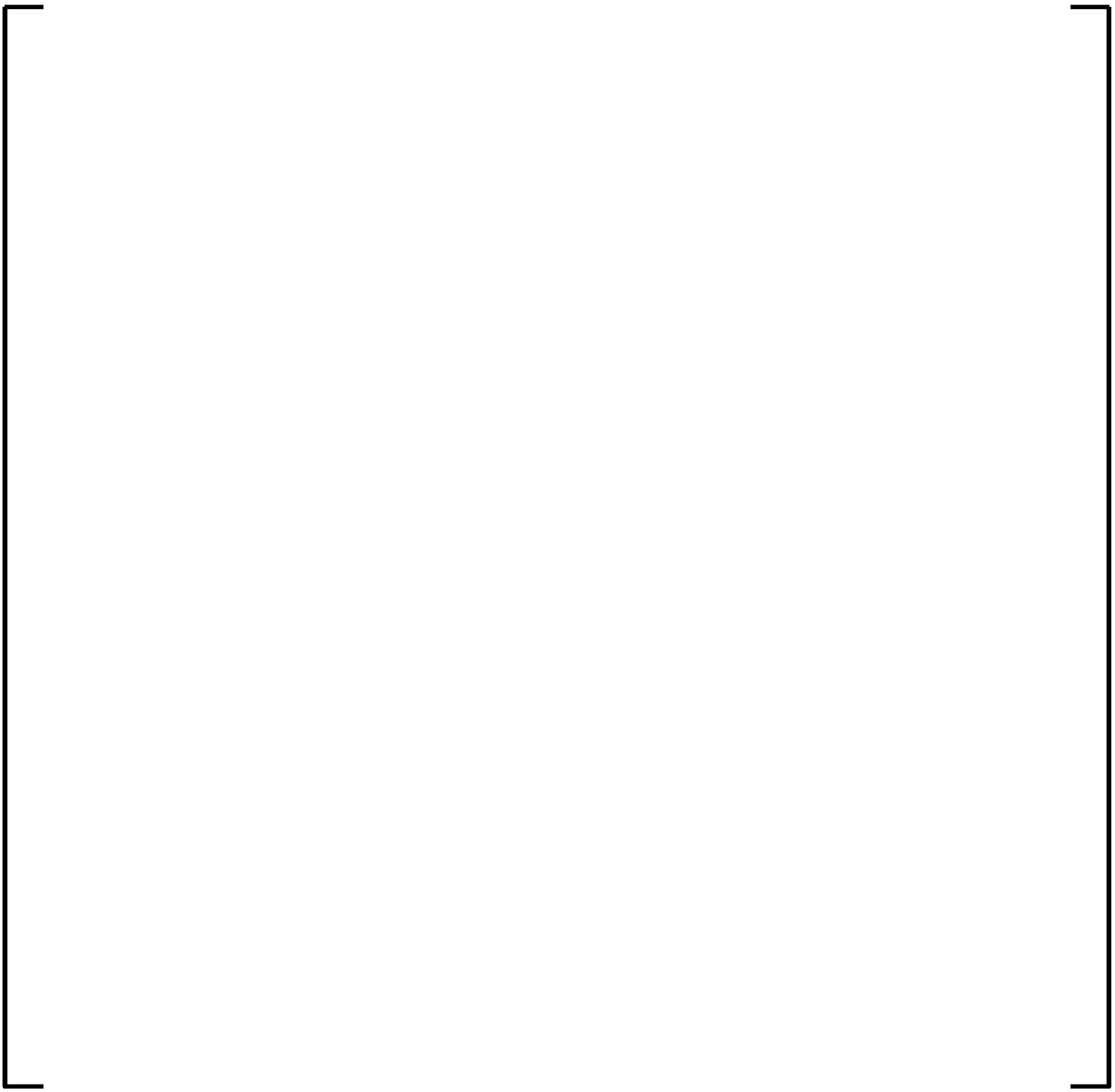

Figure 9 [

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