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ECAR-1660Results Of Reactor Physics Safety Analysis For Advanced Test Reactor (ATR) Cycle 150B

December 2010

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Changing the World's Energy Future

Idaho National Laboratory

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ENGINEERING CALCULATIONS AND ANALYSIS REPORT

Title: RESULTS OF REACTOR PHYSICS SAFETY ANALYSIS FOR ADVANCED TEST REACTOR (ATR) CYCLE 150B

ECAR No.: 1660 ECAR Rev. No.: 0 Project File No.:

1. Index Codes		
Building/Type:	SSC ID:	Site Area:

2. Quality Level and Determination No.:

QL = 1; Determination No. = RTC-000088

3. Objective/Purpose:

The Upgraded Final Safety Analysis Report (UFSAR) for the Advanced Test Reactor (ATR) requires that a reactor physics analysis be performed for each ATR cycle to assure that each ATR fuel element will operate within safety limits. The results reported in this Engineering Calculations and Analysis Report (ECAR) were obtained using the Upgraded Final Safety Analysis Report (UFSAR) PDQ X-Y model of the ATR core.

4. Conclusions/Recommendations:

Cycle 150B will run at a total core power of 107 MW for a nominal 56 days. Attached are the reactor physics data in support of the ATR Core Safety Assurance Program for Cycle 150B. The physics analysis contained herein was performed using a total core power of 106 MW with a fuel loading for 56 days. The results of the calculation show that none of the SAR/TSR limits will be violated during cycle 150B when in 2-PCP operation.

5. Review (R) and Approval (A) and Acceptance (Ac)[1]:

		Typed Name/Organization	Signature or eCR No. [2]
Performer/Author		A. W. LaPorta /W321/GB20	[signature] 8/30/11
		M. R. Holtz/W321/GB25	[signature] 8/30/2011
Data Verifier	R	C. L. Likes/W321/GB20	Cynthia L. Likes 8/30/2011
Technical Checker	R	P. A. Roth /W321/GB20	Pages checked: All [signature] 8/30/11
Independent Peer Reviewer[3]	R	N/A	
Performer's Manager	A	R.A. Jordan/W321/GB25	[signature] for RAJordan 8/31/11
Requester	Ac		
Nuclear Safety[3]	Ac	N/A	
Doc control		Michele Robb	Michele Robb 9/1/11

1 Review and Approval are required. See LWP-10200 for definitions and responsibilities.

2 Electronic Change Request (eCR) numbers in lieu of signatures on this page indicate electronic final review, approval and acceptance by the listed individuals.

3 If required, per LWP-10200.

4 Required if the ECAR contains safety software validation.

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APPENDIXES

Appendix A – Results of Reactor Physics Safety Analysis for Advanced Test Reactor (ATR) Cycle 150B

SCOPE AND BRIEF DESCRIPTION

See above

DESIGN OR TECHNICAL PARAMETER INPUT AND SOURCES

1. Natural Phenomena Hazard (NPH) category and source (Performance Category per DOE-STD-1021 and/or Seismic Design Category per ANSI/ANS 2.26) N/A
2. Load scenarios and Acceptance Criteria N/A

RESULTS OF LITERATURE SEARCHES AND OTHER BACKGROUND DATA

The analysis contained herein is performed routinely for each ATR cycle. The plan for performing and documenting the analysis is contained in the Technical Support Guide for the TSR Physics Model.

ASSUMPTIONS

See Appendix A

COMPUTER CODE VALIDATION

a. Computer type: UNIX Workstation (Castalia) See References 12 and 13 of Appendix A
b. Computer program name and revision: See Appendix A
c. Inputs (may refer to an appendix): See Appendix A
d. Outputs (may refer to an appendix): See Appendix A
e. Evidence of, or reference to, computer program validation: See Appendix A
f. Bases supporting application of the computer program to the specific physical problem: See Appendix A

DISCUSSION/ANALYSIS

See Appendix A

RECOMMENDATIONS

See Appendix A

PE STAMP

N/A

REFERENCES

See Appendix A

APPENDIXES

Appendix A - Results of Reactor Physics Safety Analysis for Advanced Test Reactor (ATR) Cycle 150B

1. Introduction

The Upgraded Final Safety Analysis Report (UFSAR) for the Advanced Test Reactor (ATR) requires that a reactor physics analysis be performed to evaluate each ATR cycle. The results reported in this Engineering Calculations and Analysis Report (ECAR) were obtained using the Upgraded Final Safety Analysis Report (UFSAR) PDQ X-Y model of the ATR core. Reference 1 identifies a UFSAR commitment to use the UFSAR PDQ X-Y model for the required physics analysis. Nuclide densities for any recycled elements used in the fuel loading of this cycle were obtained from the UFSAR RECYCLE model.

2. Assumptions

Many of the fuel safety limits are expressed in terms of effective plate power (EPP). The EPP for a fuel element plate is the product of the effective point power and the average axial peaking factor. The effective point power is defined as the product of the total core power in megawatts (MW) and the maximum point-to-core-average power density ratio. The average axial peaking factor is obtained by normalizing the axial power profile such that the maximum axial peaking factor is equal to 1.0. The normalized power profile is integrated over the 48-inch active core height and the result is divided by the active core height (48 inches). The result is defined as the average axial peaking factor. The EPP values also include normalization using the ratio of the maximum lobe power to the actual calculated lobe power.

The PDQ analysis of Cycle 150B was run for 56 days (Ref. 5) using a nominal lobe power (MW) division of 18-18-24-23-23 (NW-NE-CR-SW-SE) for a total reactor power of 106 MW. Effective plate power (EPP) values have been computed using maximum lobe powers (MW) of 21-19.5-30-26-26 (NW-NE-CR-SW-SE) for normalization (Ref. 6). Loop experiments (Ref. 5) included in the PDQ model used for this calculation are shown in Table A1, along with lobe nominal, minimum, and maximum powers (Ref. 6).

3. Data

The Cycle 150B fuel charge consists of the following fuel elements:

16 New 7F elements	16 recycle 7F elements
3 New NB elements	2 recycle NB elements
0 New YA elements	0 recycle YA elements
0 New YA...M elements	3 recycle YA...M elements

The loading placement and previous irradiation history is shown in Table A2.

When the reflector adjacent to a lobe receives sufficient radiation exposure that the ligament A stress level exceeds a value of two standard deviations less than the failure stress, the safety limits for the effective point power and EPP for fuel elements adjacent to ligament A of that lobe must be reduced. The most recent update of the reflector lifetime analysis (as required by SAR 4.2.3.6.1) provides values for relating lobe exposure (integrated power) to limiting reflector stress levels. The exposure of the reflector adjacent to the SW and SE lobes has passed the level where the ligament A stress will exceed a value of two standard deviations less than the failure stress. This ECAR documents the reduction in safety limits in those two lobes.

When the inspection of a new fuel element finds a reduced width in a coolant channel between fuel plates, the effective plate power limit for the plates adjacent to the narrow coolant channel must be reduced. The PDQ model used in this analysis tracks the power in 11 of the 19 fuel element plates. Those plates have numbers 1, 2, 3, 5, 8, 11, 15, 16, 17, 18, and 19. When an element has a reduced width in any coolant channel, the plate power limit will be restricted for any adjacent tracked plate or for the nearest tracked plate if there is no adjacent tracked plate. The fuel elements in the fuel loading for this cycle do not have any restrictions.

4. Analysis and Calculations

The calculation was performed using the PDQWS computer code on the castalia workstation. PDQWS results were processed using a suite of codes, including most importantly, ROSUB, PQMAP, GRAMS, TRNF, GOPPNP, LMFIS, POWCOR, and CRITOS. The cross-sections included in the input deck were generated using the codes: COMBINE, SCAMP, SCRABL, and RZPGM. Fuel inventory data for use in PDQWS is maintained by the codes: RECINV and RECYCLE.

The ATR PDQ model was run to represent the performance of the reactor during normal operation of Cycle 150B. The shim positions corresponding to this operation are shown in Table A5. The lobe powers and values of $K_{effective}$ for this run are shown in Table A6.

The ATR PDQ model was also run to represent the "worst-case" shim misalignment accident for each lobe. The shim positions corresponding to each misalignment configuration are shown in Table A7 and the resulting lobe powers and values of $K_{effective}$ are shown in Table A8.

5. Results and Conclusions

The PDQ analysis tracks the EPP in plate 19 and in ten of the remaining 18 plates of each of the 40 elements. The most limiting value in each lobe has been determined by evaluating the EPP in each of the 10 tracked inner fuel plates in each of the 8 elements of each lobe, and then factoring in any restrictions that have been placed on each fuel plate. The value that results from this analysis is often the maximum EPP value in the lobe, but occasionally a restriction causes a plate with less than the maximum EPP to be more limiting. The EPP value can be compared to the effective plate power limit and used in establishing acceptance criteria for the surveillance of the Lobe Power Calculation and Indication System (LPCIS) [TSR 3.6.1 (b)].
Table 1 shows the limits for the EPP as specified in ATR Technical Safety Requirements 3.6.1(a) (Table 3.6.1-1) for the inner plates along with the most limiting calculated EPP value for the inner plates in each lobe. Inner fuel plates are all plates except plate 19.

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Table 1. Limiting Inner Plate EPP by Lobe

Lobe	Effective Plate Power Limit		Inner Plate Most Limiting EPP By Lobe				
	2 PCP	3 PCP	Pos.	Plate	Restricted to (%) of limit	Days	EPP
NW	417	443	F-32	5	100	0	234
NE	417	443	F-9	5	100	0	221
CR	417	443	F-21	5	100	3	257
SW	417	443	F-22	5	100	0	239
SE	417	443	F-19	5	100	0	241

The most limiting EPP in each lobe is less than the operating limit for 2 primary coolant pumps (PCP), so two-pump operation will be possible for this cycle.

Table 2 shows the most limiting inner plate EPP value in each quadrant rather than in each lobe. Center lobe elements have been combined into the adjacent corner lobe to make the four quadrants.

Table 2. Limiting Inner Plate EPP by Quadrant

Quadrant	Effective Plate Power Limit		Inner Plate Most Limiting EPP By Quadrant				
	2 PCP	3 PCP	Pos.	Plate	Restricted to (%) of limit	Days	EPP
NW	417	443	F-32	5	100	0	234
NE	417	443	F-9	5	100	0	221
SW	417	443	F-21	5	100	3	257
SE	417	443	F-20	5	100	3	251

Table 3 shows the limits for the EPP as specified in ATR Technical Safety Requirements 3.6.1(a) (Table 3.6.1-1) for plate 19 along with the most limiting calculated EPP value for plate 19 in each lobe.

Table 3. Limiting Plate 19 EPP by Lobe

Lobe	Effective Plate Power Limit		Plate 19 Most Limiting EPP By Lobe				
	2 PCP	3 PCP	Pos.	Plate	Restricted to (%) of limit	Days	EPP
NW	417	445	F-33	19	100	0	155
NE	417	445	F-8	19	100	0	169
CR	417	445	F-21	19	100	38	148
SW	417	445	F-23	19	100	0	209
SE	417	445	F-18	19	100	0	209

The plate 19 most limiting EPP values for each lobe are within the allowable TSR EPP limits for 2-PCP operation. Therefore, 2-PCP operation is still acceptable for this cycle.

The most limiting EPP values calculated for Cycle 150B elements at each time step are given in Table 4.

Table 4. Limiting EPP at Each Time Step

Plate Type	EPP Limit 2 PCP	Pos.	Plate	Restricted to (%) of limit	Days[a]	Cycle 150B Most Limiting EPP
19	417	18,23	19	100	0	209
Inner	417	21	5	100	0	245
19	417	23	19	100	3	195
Inner	417	21	5	100	3	257
19	417	23	19	100	10	194
Inner	417	21	5	100	10	252
19	417	23	19	100	17	190
Inner	417	21	5	100	17	250
19	417	23	19	100	24	186
Inner	417	21	5	100	24	246
19	417	23	19	100	31	185
Inner	417	21	5	100	31	237
19	417	23	19	100	38	180
Inner	417	21	5	100	38	227
19	417	23	19	100	45	173
Inner	417	19,21,22	5	100	45	218
19	417	23	19	100	52	164
Inner	417	21	5	100	52	213
19	417	23	19	100	56	160
Inner	417	21	5	100	56	209

a Data for the 0-day ganged outer shim case is not included.

Exposure exceeded the value for the limiting A-ligament stress level in the SW and SE lobe during cycle 147A. Core positions F-24 through F-27 in the SW lobe and F-14 through F-17 in the SE lobe are adjacent to ligament A. Therefore the EPP limits in Tables 1-4 above are not applicable to these positions and reduced values as specified in ATR Technical Safety Requirements 3.6.1(a) (Table 3.6.1-1) must be used. The most limiting EPP values for these positions are given below along with the $<2\sigma$ limits.

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Table 5. Limiting EPP for core positions for which Ligament A stress is <2σ to cracking: F-14 through F-17 and F-24 through F-27

Lobe/Plate	Effective Plate Power Limit		Cycle 150B Most Limiting EPP for Ligament A (<2σ) Positions By Lobe				
	2 PCP	3 PCP	EPP	Pos.	Plate	Days	Restricted to (%) of limit
SW/Inner Plates	406	431	186	24	15	56	100
SW/Plate 19	358	357	167	24	19	3	100
SE/Inner Plates	406	431	185	17	15	56	100
SE/Plate 19	358	357	168	17	19	3	100

The elements in several positions of the fuel loading for this cycle, reach a fission density greater than 1.5×10^{21} during the cycle. For these elements, keeping the effective point powers less than the appropriate limits will prevent blistering of the fuel by ensuring that the maximum temperature will be at least 2σ less than 500°F (533°K) as required under UFSAR 4.2.1 as defined in Reference 4. Table 6 shows in which positions the elements have exceeded the 1.5×10^{21} limit at each time step.

Table 6. Fuel Element Positions for which the fission density is greater than 1.5×10^{21}

Days	Position Numbers
0	10
3	10
10	1,10,20,30,31
17	1,10,11,20,21,30,31,40
24	1,10,11,20,21,30,31,40
31	1,10,11,20,21,30,31,40
38	1,10,11,20,21,33,31,40
45	1,10,11,15,16,20,21,25,26,30,31,34,35,36,37,40
52	1,10,11,15,16,20,21,25,26,30,31,33,34,35,36,37,40
56	1,10,11,15,16,20,21,25,26,30,31,33,34,35,36,37,38,40

Once an element exceeds 1.5×10^{21} fission density, its effective point power must not exceed the appropriate limit for its position as defined in Reference 4. Tables 7 and 8 identify the calculated effective point power for the most limiting element in each lobe for an inner plate and plate 19. Lobes with "NA" entries do not have any elements that exceed 1.5×10^{21} fission density during the cycle.

Table 7. Inner Plate Limiting Effective Point Power by lobe for fission density greater than 1.5×10^{21}

Lobe	Effective Point Power Limit		Cycle 150B Most Limiting Effective Point Power By Lobe				
	2 PCP	3 PCP	Pos.	Plate	Restricted to (%) of limit	Days	EPtP
NW	446	465	F-33	15	100	52	186
NE	446	465	N/A	N/A	100	N/A	N/A
CR	446	465	F-21	5	100	17	315
SW	435	453	F-25	15	100	52,56	179
SE	435	453	F-15	15	100	52,56	179

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Table 8. Plate 19 Limiting Effective Point Power by lobe for fission density greater than 1.5×10^{21}

Lobe	Effective Point Power Limit		Cycle 150B Most Limiting Effective Point Power By Lobe				
	2 PCP	3 PCP	Pos.	Plate	Restricted to (%) of limit	Days	EPtP
NW	411	428	F-33	19	100	52	149
NE	411	428	N/A	19	100	N/A	N/A
CR	411	428	F-21	19	100	38	175
SW	411	428	F-25	19	100	56	149
SE	411	428	F-16	19	100	56	144

The worst-case LOBE powers equivalent to the TSR 3.6.1a, Table 3.6.1-1 effective plate power limits are shown in Table 9 on the next page. The worst-cases were found by simulating a lobe power unbalance accident using maximum shim unbalances in the PDQ model and the results are subsequently scaled to the limiting effective plate power.

Table 9. Worst-case Lobe Powers at Effective Plate Power Limit

Lobe	Cycle Maximum LOBE Power (MW)	Maximum Unbalanced LOBE Power (MW)	Type of Position, Type of Plate	Limiting EPP at Maximum Unbalanced LOBE Power (MW)	Position	Plate	Restriction	Transient Effective Plate Power Limits and Overpower Ratios (MW)	Reference Lobe Power for Quadrant ΔT Setpoints (MW)
NW	21.0	27.66	All, inner plates	204	F-32	5	1.00	659/1.45 = 454	61.5*
			All, plate 19	187	F-38	19	1.00	659/1.45 = 454	67.1
NE	19.5	26.54	All, inner plates	207	F-9	5	1.00	659/1.45 = 454	58.2*
			All, plate 19	193	F-3	19	1.00	659/1.45 = 454	62.4
C	27.0	30.64	All, inner plates	221	F-21	5	1.00	659/1.45 = 454	62.9*
			All, plate 19	144	F-21	19	1.00	659/1.45 = 454	96.6
SW	26.0	34.47	All, inner plates	252	F-24	15	1.00	659/1.45 = 454	62.1
			All, plate 19	249	F-24	19	1.00	659/1.45 = 454	62.8
			< 2 sigma, inner plates	252	F-24	15	1.00	641/1.45 = 442	60.4
			< 2 sigma, plate 19	249	F-24	19	1.00	490/1.37 = 357	49.4*
SE	26.0	35.42	All, inner plates	259	F-17	15	1.00	659/1.45 = 454	62.0
			All, plate 19	255	F-17	19	1.00	659/1.45 = 454	63.0
			< 2 sigma, inner plates	259	F-17	15	1.00	641/1.45 = 442	60.4
			< 2 sigma, plate 19	255	F-17	19	1.00	490/1.37 = 357	49.5*

* indicates minimum value for the lobe

The resulting worst-case lobe powers are used for establishing compliance with Technical Safety Requirement 3.1.1(a) (Table 3.1.1-1 SR#03) for the quadrant differential temperature set point. The effective plate power limits utilized the methods given in Reference 3. Each line in the table selects the element in a specific category that has the most limiting EPP once the individual plate restrictions have been considered. Values in the rightmost column are calculated by multiplying the values in columns 3, 8, and 9 and then dividing by the value in column 5. If the values in the rightmost column were smaller than the values in column 2, it would be necessary to reduce the requested maximum lobe powers accordingly. For this cycle no such adjustment will be necessary.

Table A9 lists the fuel element powers for each time step of the cycle. In order to find the maximum expected fuel element power for the cycle, the element powers in Table A9 are scaled to the lobe maximum power by multiplying by the ratio of the lobe maximum power divided by the actual lobe power. After examining all of the scaled fuel element powers for time steps beyond xenon equilibrium, we find that the maximum expected fuel element power during Cycle 150B is 4.298 MW in core position F-21.

The maximum calculated point-to-average power density ratio at a distance 90% from the edge of the fuel in plate 19 for any element is 2.51 in position F-18 for the time step 0.

The preliminary startup power division normalized to a total core power of 250 MW is: 42.5-38.9-56.3-56.2-56.0 (NW-NE-C-SW-SE).

The reactivity estimates and the fission density limits as given in UFSAR Section 4.2.1.2.3 are shown in Table 10.

Table 10. Reactivity Estimates and Fission Density Limits

	Reactivity Estimate[a]		**Fission Density Limit (2.3×10^{21} fissions/cc)**	
Lobe	**MWd**	**Time in Cycle**[b] **(Days)**	**MWd**	**Time in Cycle**[c] **(Days)**
NW	1014	56.3	1942	92.4
NE	1102	61.2	1970	101.0
C	---	---	1394	46.4
SW	1461	63.5	2316	89.0
SE	1450	63.0	2323	89.3

a. The reactivity estimates were obtained using the XSPRJ method.
b. The Time in Cycle is based on the nominal power division of 18-18-24-23-23 (NW-NE-CR-SW-SE).
c. The Time in Cycle is based on the maximum power division of 21-19.5-30-26-26 (NW-NE-CR-SW-SE).

The results above show sufficient reactivity to sustain the requested lobe power for the cycle length of 56 days. The results also show that the fission density limits should not be exceeded for a cycle length of 56 days in every lobe except the center (CR) lobe. The time in the cycle required to reach the CR lobe fission density limit was calculated using a maximum lobe power of 30 MW. To achieve the fission density limit during a 56 day cycle, a CR lobe average power of approximately 27 MW would have to be sustained. Calculations and operational experience indicate that the CR lobe average power over the entire cycle will be similar to Cycle 149B, which had an average CR lobe power of 24.2 MW. Thus, exceeding the fission density limit is considered improbable. Nuclear Engineering will track actual CR Lobe MWds to ensure fission density limits in the CR Lobe are not exceeded during the cycle. The reactivity and fission density data are shown in Figures A1 and A2.

All of the elements in the fuel loading for Cycle 150B are expected to have further recycle potential after the nominal operation of Cycle 150B except for the following:

Pos.	Serial No.
1	XA132T
10	YA497TM
20	YA476TM
21	XA856T
30	YA552TM
31	XA881T

The methods used in this analysis are found in References 7 and 8.

6. Hardware and Software

Calculations were performed on the castalia workstation – cpu-property number 380414. The analysis codes along with their V&V tracking number are shown in Table 11. The V&V is documented in References 11 and 12.

Table 11. Computer Codes and V&V Tracking Numbers

Software Application Name	Version	Checksum Value	Enterprise Architecture Tracking Number
cmpr	1	1381	114931
critos	2	5760	114934
Fispk	-	50065	224935
gopp1	02/99	37552	207598
grams	2	61942	114939
Lmfis	1	22139	114940
mxfis	-	4291	-
Pdq	1	61283	67621
powcor	1	4227	67618
pqmap	1	8421	114945
pqmapin	-	15808	-
pqxspl	1	16060	114947
recinv	1	11392	114949
recycle	1	56856	114950
rosub	2	29380	114952
rpcr2	-	55876	-
rzpgm	1	34117	114953
rzread	-	43442	114954
Trnf	1	2014	114957
updatr	1	25709	114958

7. References

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11. P. A. Roth, Verification and Validation of ATR Physics Analysis Software on Workstation Castalia, ECAR-516, February, 2009.
12. Roth, P. A., Verification and Validation of ATR Physics Analysis Software, rzpgm and rzread, on Workstation Castalia, ECAR-593, April 29, 2009.

Table A1. Experimental Designations and Nominal Power Division for ATR Cycle 150B[5,6]

Lobe	Power	Loop Experiments
NW	18 (+3 / -3)	2E/NW-160 R#2E
N	-	1D/N-105 Var Flux/Temp Corr. R#0
NE	18 (+1.5 / -2)	MICE Facility with 2 MRW B/Us and Structural 8A & 8B
W	-	1C/W-75 Med. Corr. R#0
C	24 (+3 / -6)	AFIP-7 Four Fuel Plate Experiment
E	-	7-Pin Flux Trap Irradiation Facility with AFC 2D and 2E in E1-E2 respectively, dummy in E3, UW-2 in E4, Drex-A in E5, and Aluminum Fillers in E6-E7
SW	23 (+3 / -3)	2D/SW-185 STD BU R#0
S	-	AGC-2
SE	23 (+3 / -3)	2B/SE-191 STD BU R#1

Table A2. Summary of Fuel Load for Cycle 150B

Core	Serial	Content		Total	Irradiation History							
Pos.	No.	^{235}U	^{10}B	MWD	Cycle	Pos.	Cycle	Pos.	Cycle	Pos.	Cycle	Pos.
1	XA132T	792	0.080	1659	131A-1	19	135A-1	15				
2	XA926T	1075	0.660									
3	XA932T	1075	0.660									
4	XA228T	943	0.259	927	148B-1	7						
5	XA764TNB	925	0.000	663	149A-1	9						
6	XA892T	960	0.287	663	149A-1	3						
7	XA939T	1075	0.660									
8	XA938T	1075	0.660									
9	XA783TNB	1075	0.000									
10	YA497TM	726	0.045	1777	141A-1	27	143B-1	33				
11	XA820T	788	0.069	2169	146A-1	15	148A-1	6				
12	XA941T	1075	0.660									
13	XA942T	1075	0.660									
14	XA943T	1075	0.660									
15	XA911T	931	0.228	847	149A-1	13						
16	XA920T	933	0.234	883	149A-1	24						
17	XA944T	1075	0.660									
18	XA946T	1075	0.660									
19	XA957T	1075	0.660									
20	YA476TM	770	0.064	1828	134B-1	15	149A-1	34				
21	XA856T	850	0.136	1300	146A-1	29						
22	XA958T	1075	0.660									
23	XA959T	1075	0.660									
24	XA960T	1075	0.660									
25	XA916T	915	0.222	847	149A-1	19						
26	XA919T	913	0.194	883	149A-1	23						
27	XA961T	1075	0.660									
28	XA962T	1075	0.660									
29	XA963T	1075	0.660									
30	YA552TM	757	0.059	1923	145B-1	4	146B-1	27				
31	XA881T	795	0.074	1739	148A-1	38	149A-1	26				
32	XA780TNB	1075	0.000									
33	XA915T	919	0.203	847	149A-1	18						
34	XA871T	893	0.186	1021	146B-1	12						
35	XA758TNB	886	0.000	1020	145B-1	8						
36	XA825T	861	0.143	1191	144B-1	29						
37	XA229T	910	0.195	927	148B-1	8						
38	XA923T	921	0.234	883	149A-1	29						
39	XA781TNB	1075	0.000									
40	XA846T	789	0.069	2092	146A-1	5	148B-1	14				

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Table A3. Plate Restrictions for Fuel Loaded in Cycle 150B[9,10]

Core Pos.	Serial No.	Restriction	Restricted Plates (of those represented in the PDQ model)
1	XA132T		
2	XA926T		
3	XA932T		
4	XA228T		
5	XA764TNB		
6	XA892T		
7	XA939T		
8	XA938T		
9	XA783TNB		
10	YA497TM		
11	XA820T		
12	XA941T		
13	XA942T		
14	XA943T		
15	XA911T		
16	XA920T		
17	XA944T		
18	XA946T		
19	XA957T		
20	YA476TM		
21	XA856T		
22	XA958T		
23	XA959T		
24	XA960T		
25	XA916T		
26	XA919T		
27	XA961T		
28	XA962T		
29	XA963T		
30	YA552TM		
31	XA881T		
32	XA780TNB		
33	XA915T		
34	XA871T		
35	XA758TNB		
36	XA825T		
37	XA229T		
38	XA923T		
39	XA781TNB		
40	XA846T		

Table A4. Capsule Facility Loading Used in ATR Cycle 150B Analysis[5]

Facility	Description	Reference
E-1	AFC-2D	KEB-11-11,rev.1
E-2	AFC-2E	KEB-11-11,rev.1
E-3	Dummy	KEB-11-11,rev.1
E-4	UW-2	KEB-11-11,rev.1
E-5	Drex-A	KEB-11-11,rev.1
E-6	Aluminum Filler	KEB-11-11,rev.1
E-7	Aluminum Filler	KEB-11-11,rev.1
SFT	AGC-2	MED-01-11
A-1	HSA Cobalt	BJH-2-92
A-2	HSA Cobalt	BJH-2-92
A-3	IASFR	
A-4	HSA Cobalt	BJH-2-92
A-5	HSA Cobalt	BJH-2-92
A-6	HSA Cobalt	BJH-2-92
A-7	HSA Cobalt	BJH-2-92
A-8	HSA Cobalt	BJH-2-92
A-9	HSA Cobalt	RAK-04-02
A-10	AFC-3A	KEB-13-11
A-11	AFC-3B	KEB-13-11
A-12	SFROP	
A-13	EPRI –ZG-D	GWW-06-11
A-14	EPRI –ZG-B	GWW-06-11
A-15	EPRI–ZG-C	GWW-06-11
A-16	EPRI –ZG-A	GWW-06-11
B-1	YSFR	
B-2	USU-1	DJL-02-11
B-3	HSA Cobalt	BJH-73-88
B-4	HSA Cobalt	BJH-73-88
B-5	HSA Cobalt	BJH-73-88
B-6	HSA Cobalt	BJH-73-88
B-7	HSIS (Drexel shuttles)	GWW-08-11

Table A4. Continued

Facility	Description	Reference
B-8	YSFR	
B-9	RERTR-12-3	GNH-05-11
B-10	Aluminum Filler	
B-11	Aluminum Filler	
B-12	AGR-2	SBG-01-11, Rev.1
H-1	Hafnium Shim	HAW-02-11
H-2	HSA Cobalt	TMS-06-08
H-3	N-16 MONITOR	
H-4	HSA Cobalt	TMS-06-08
H-5	Hafnium Shim	HAW-02-11
H-6	HSA Cobalt	TMS-06-08
H-7	HSA Cobalt	TMS-06-08
H-8	HSA Cobalt	TMS-06-08
H-9	Hafnium Shim	HAW-02-11
H-10	HSA Cobalt	TMS-06-08
H-11	N-16 MONITOR	
H-12	HSA Cobalt	TMS-06-08
H-13	Hafnium Shim	HAW-02-11
H-14	HSA Cobalt	TMS-06-08
H-15	HSA Cobalt	TMS-06-08
H-16	HSA Cobalt	TMS-06-08
I-1 thru I-20	Beryllium Filler	
I-21	Aluminum Filler	
I-22	UCSB-2	TLM-1-11
I-23	Aluminum Filler	
I-24	Aluminum Filler	

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Table A5. Summary of ATR Shim Positions for ATR Cycle 150B

Time At Power (Days)	NW LOBE Outer Shims (Deg.)	NW LOBE Neck Shims Inserted	NE LOBE Outer Shims (Deg.)	NE LOBE Neck Shims Inserted	SW LOBE Outer Shims (Deg.)	SW LOBE Neck Shims Inserted	SE LOBE Outer Shims (Deg.)	SE LOBE Neck Shims Inserted
0	56.6	1 2 3 4 5 6	56.6	1 2 3 4 5 6	56.6	1 2 3 5 6	56.6	1 2 3 5 6
0	51.2	1 2 3 4 5 6	56.6	1 2 3 4 5 6	56.6	1 2 3 5 6	56.6	1 2 3 5 6
3	85.4	1 2 3 4 5 6	85.4	1 2 3 4	85.4	1 2 3 5	85.4	1 2 3 5
10	85.4	1 2 3 4 5	85.4	1 2 3	85.4	1 2 3 5	85.4	1 2 3
17	85.4	1 2 3 4	85.4	1 2 3	85.4	1 2 3	85.4	1 2
24	85.4	1 2 3 4	85.4	1 2	85.4	1 2	85.4	1 2
31	85.4	1 2 3	85.4	1	85.4	1	85.4	
38	85.4	1 2	85.4		85.4		85.4	
45	85.4		89.8		89.8		89.8	
52	100.1		104.2		104.2		104.2	
56	111.7		111.7		116.4		116.4	

Table A6. Summary of ATR Core Power and Calculated $K_{effective}$ for ATR Cycle 150B

Time at Power (Days)	Total Core Power (MW)	Lobe Powers (MW) NW	NE	CR	SW	SE	$K_{effective}$
0	106	18.0	16.5	23.9	23.8	23.8	0.9898
0	106	17.3	16.6	24.0	24.0	24.1	0.9889
3	106	18.1	17.5	21.6	24.3	24.6	0.9894
10	106	18.2	17.8	21.6	23.7	24.7	0.9909
17	106	18.2	17.4	21.6	24.1	24.7	0.9929
24	106	17.8	17.6	21.8	24.3	24.6	0.9923
31	106	17.6	17.6	22.6	23.8	24.5	0.9971
38	106	17.7	17.7	23.0	23.6	24.0	0.9966
45	106	17.7	17.9	22.9	23.7	23.8	0.9958
52	106	17.8	18.2	21.6	24.0	24.3	0.9986
56	106	17.9	18.2	20.9	24.3	24.7	1.0006

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Table A7. Summary of ATR Shim Positions for ATR Cycle 150B Worst Case Calculations

	NW LOBE		NE LOBE		SW LOBE		SE LOBE	
Lobe	(Deg.)	Inserted	(Deg.)	Inserted	(Deg.)	Inserted	(Deg.)	Inserted
NW	153.9	1 1 1 1 1 1	85.4	1 1 1 1 0 0	85.4	1 1 1 0 1 0	0.0	1 1 1 0 1 0
NE	85.4	1 1 1 1 1 1	153.9	1 1 1 1 0 0	0.0	1 1 1 0 1 0	85.4	1 1 1 0 1 0
CR	0.0	0 0 0 0 0 0	0.0	0 0 0 0 0 0	0.0	0 0 0 0 0 0	0.0	0 0 0 0 0 0
SW	85.4	1 1 1 1 1 1	0.0	1 1 1 1 0 0	153.9	1 1 1 0 1 0	85.4	1 1 1 0 1 0
SE	0.0	1 1 1 1 1 1	85.4	1 1 1 1 0 0	85.4	1 1 1 0 1 0	153.9	1 1 1 0 1 0

Table A8. Summary of ATR Core Power and Calculated $K_{effective}$ for Worst-Case Calculations

Lobe	Total Core Power (MW)	Lobe Powers (MW) NW	NE	CR	SW	SE	$K_{effective}$
NW	106	27.6562	18.2422	21.7260	24.7819	13.5937	0.986084
NE	106	18.8167	23.5390	21.7366	13.6294	25.2784	0.986069
CR	106	18.4847	16.8893	30.6425	20.1251	19.8585	0.980801
SW	106	17.0810	10.2780	20.9466	34.4675	23.2269	0.997213
SE	106	10.2645	16.6639	20.8760	22.7800	35.4157	0.998105

Table A9. Summary of Fuel Element Powers for ATR Cycle 150B

Time At Power (Days)	Total Core Power (MW)	Power (MW) For Fuel Element In Core Positions 1-10									
		1	2	3	4	5	6	7	8	9	10
0	106	2.7	2.7	2.3	1.6	1.4	1.3	1.7	2.4	3.0	2.7
0	106	2.7	2.7	2.3	1.7	1.4	1.4	1.7	2.4	3.0	2.7
3	106	2.5	2.7	2.4	1.8	1.7	1.7	1.9	2.4	2.9	2.5
10	106	2.5	2.8	2.4	1.9	1.7	1.7	1.9	2.5	3.0	2.5
17	106	2.5	2.7	2.3	1.8	1.7	1.6	1.9	2.4	2.9	2.5
24	106	2.6	2.8	2.4	1.8	1.7	1.7	1.9	2.4	3.0	2.5
31	106	2.7	2.8	2.4	1.8	1.6	1.6	1.9	2.4	3.0	2.6
38	106	2.8	2.9	2.4	1.8	1.6	1.6	1.9	2.5	3.0	2.7
45	106	2.7	2.9	2.4	1.8	1.7	1.7	1.9	2.5	3.0	2.6
52	106	2.6	2.8	2.4	1.9	1.8	1.8	2.1	2.5	2.9	2.5
56	106	2.5	2.7	2.4	2.0	1.9	1.9	2.1	2.5	2.8	2.4

Time At Power (Days)	Total Core Power (MW)	Power (MW) For Fuel Element In Core Positions 11-20									
		11	12	13	14	15	16	17	18	19	20
0	106	3.1	3.2	3.2	2.8	2.3	2.3	2.9	3.5	3.6	3.2
0	106	3.1	3.3	3.2	2.8	2.3	2.4	2.9	3.5	3.7	3.3
3	106	2.8	3.0	3.2	2.9	2.8	2.8	3.1	3.4	3.4	2.9
10	106	2.8	3.1	3.2	3.0	2.8	2.8	3.1	3.5	3.4	2.9
17	106	2.8	3.1	3.2	2.9	2.7	2.8	3.1	3.5	3.5	3.0
24	106	2.8	3.1	3.2	2.9	2.7	2.7	3.0	3.5	3.5	2.9
31	106	3.0	3.2	3.2	2.9	2.6	2.7	3.0	3.5	3.5	3.1
38	106	3.0	3.1	3.1	2.8	2.5	2.6	2.9	3.4	3.5	3.1
45	106	2.9	3.1	3.1	2.8	2.6	2.6	2.9	3.3	3.4	3.0
52	106	2.8	3.0	3.1	3.0	2.7	2.8	3.1	3.4	3.3	2.8
56	106	2.7	3.0	3.1	3.1	2.8	2.9	3.2	3.4	3.3	2.7

Table A9. Continued

Time At Power (Days)	Total Core Power (MW)	Power (MW) For Fuel Element In Core Positions 21-30									
		21	22	23	24	25	26	27	28	29	30
0	106	3.4	3.5	3.5	2.9	2.3	2.3	2.8	3.3	3.4	3.0
0	106	3.4	3.6	3.5	2.9	2.3	2.3	2.8	3.3	3.4	3.0
3	106	3.1	3.2	3.4	3.0	2.7	2.7	2.9	3.2	3.1	2.7
10	106	3.0	3.2	3.3	2.9	2.6	2.6	2.8	3.1	3.1	2.6
17	106	3.1	3.3	3.4	3.0	2.6	2.6	2.9	3.1	3.2	2.6
24	106	3.1	3.3	3.4	3.0	2.6	2.6	2.9	3.2	3.2	2.7
31	106	3.2	3.3	3.4	2.9	2.5	2.5	2.8	3.1	3.2	2.8
38	106	3.3	3.3	3.3	2.9	2.5	2.5	2.8	3.1	3.2	2.8
45	106	3.2	3.3	3.3	2.9	2.5	2.5	2.8	3.1	3.2	2.8
52	106	3.0	3.2	3.3	3.0	2.7	2.7	2.9	3.1	3.1	2.6
56	106	2.9	3.1	3.3	3.1	2.8	2.8	3.0	3.1	3.1	2.6

Time At Power (Days)	Total Core Power (MW)	Power (MW) For Fuel Element In Core Positions 31-40									
		31	32	33	34	35	36	37	38	39	40
0	106	3.0	3.3	2.6	1.8	1.5	1.4	1.8	2.5	3.2	2.8
0	106	3.0	3.2	2.5	1.7	1.3	1.3	1.7	2.4	3.1	2.8
3	106	2.6	2.9	2.5	2.0	1.8	1.7	2.0	2.4	2.8	2.5
10	106	2.6	2.9	2.5	2.0	1.8	1.7	2.0	2.5	2.9	2.5
17	106	2.6	3.0	2.5	1.9	1.7	1.7	1.9	2.4	3.0	2.5
24	106	2.6	3.0	2.4	1.9	1.7	1.6	1.9	2.4	2.9	2.5
31	106	2.6	3.0	2.4	1.8	1.6	1.6	1.8	2.4	2.9	2.5
38	106	2.7	3.1	2.4	1.8	1.6	1.6	1.8	2.4	3.0	2.6
45	106	2.8	3.1	2.4	1.8	1.6	1.6	1.8	2.4	3.1	2.8
52	106	2.7	2.9	2.4	1.9	1.7	1.7	1.9	2.4	2.9	2.6
56	106	2.6	2.9	2.3	1.9	1.8	1.8	2.0	2.4	2.8	2.5

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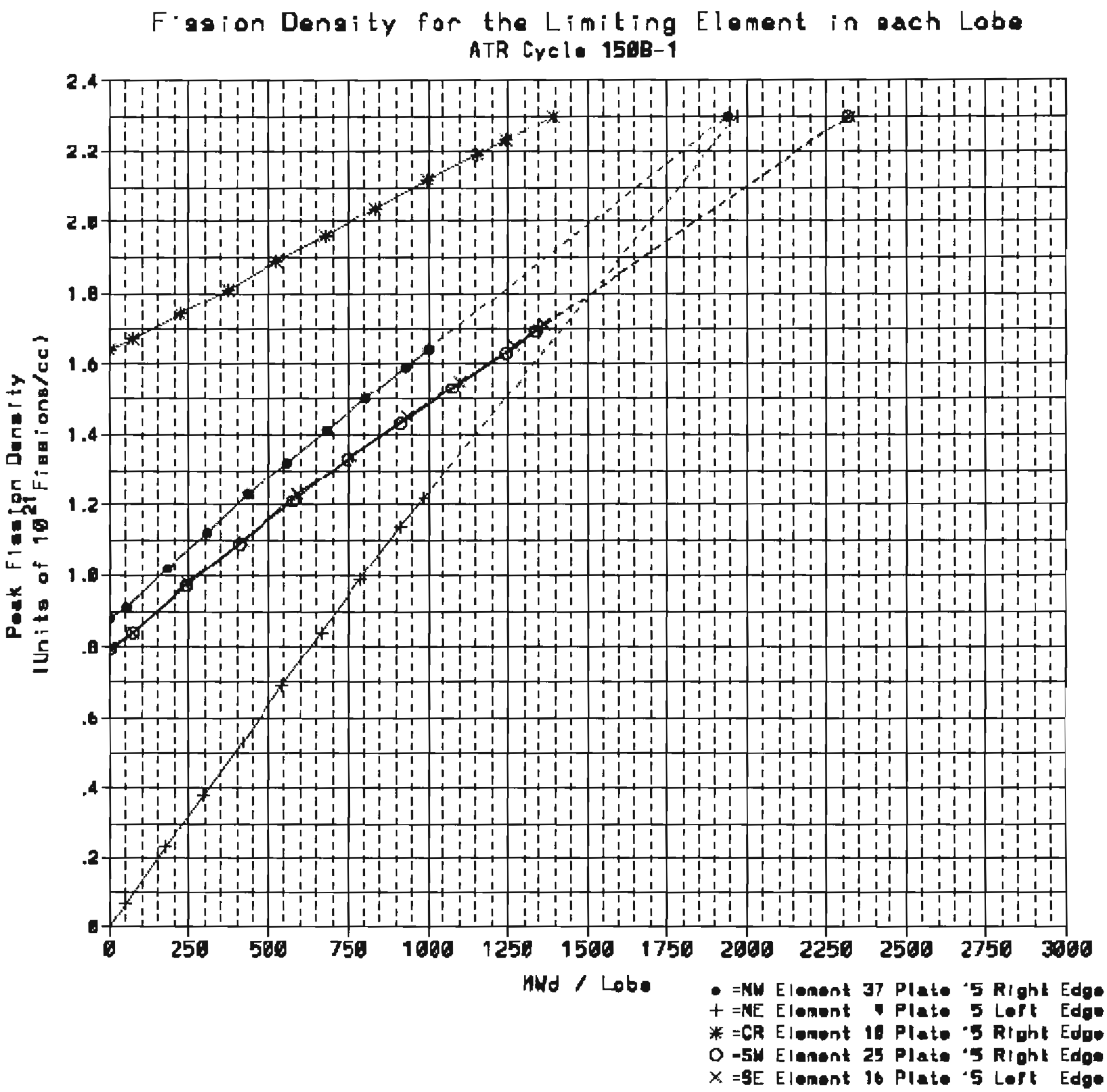

Figure A1. Fission Density for the Limiting Element in each Lobe For Cycle 150B-1

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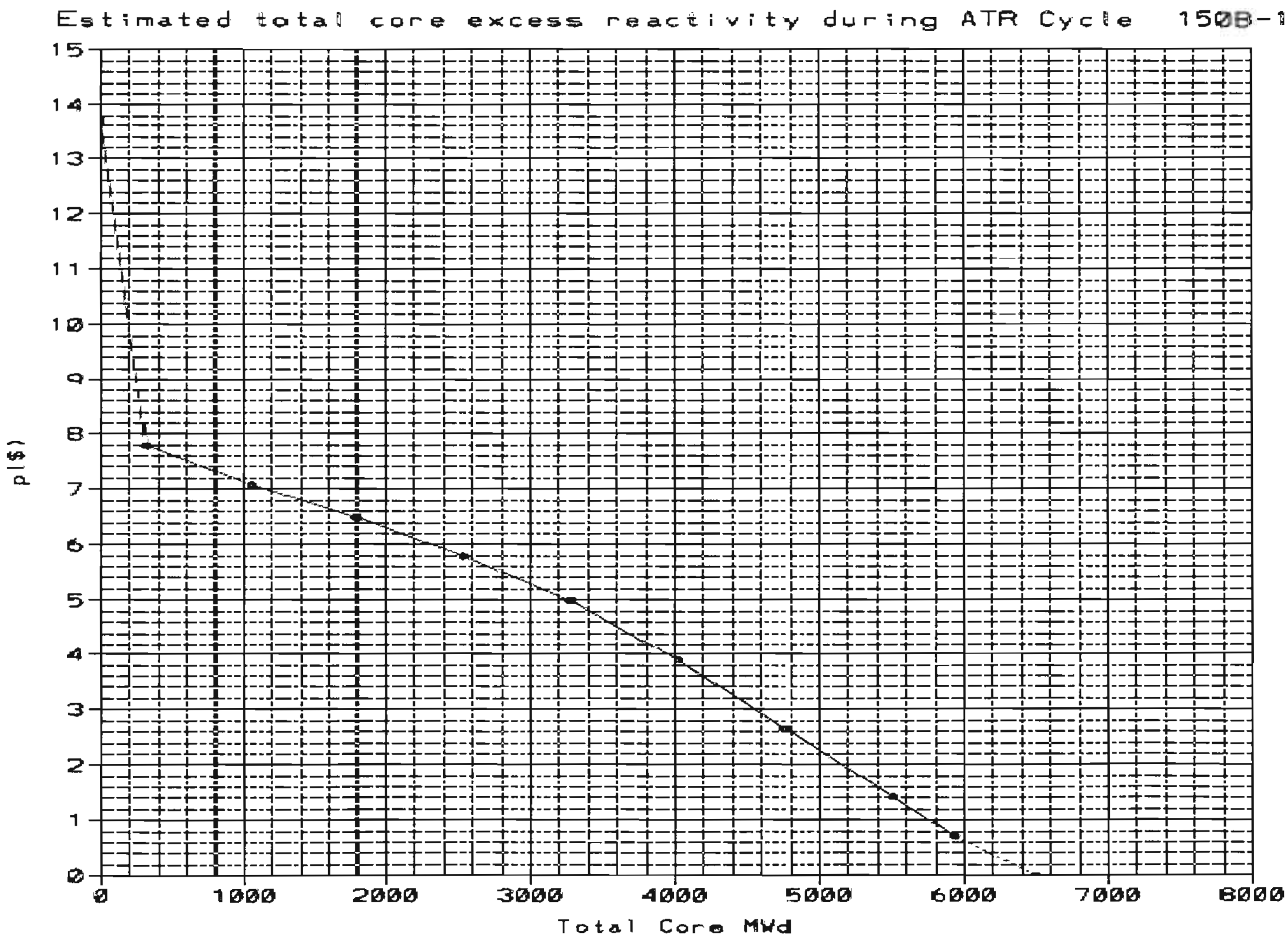

Figure A2. Estimated Total Core Excess Reactivity During ATR Cycle 150B-1