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ECAR 1253 Results Of Reactor Physics Safety Analysis For Advanced Test Reactor (ATR) Cycle 148B

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Changing the World's Energy Future

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ENGINEERING CALCULATIONS AND ANALYSIS REPORT

Title: Results of Reactor Physics Safety Analysis for Advanced Test Reactor (ATR) Cycle 148B

ECAR No.: 1253 ECAR Rev. No.: 0 Project File No.: N A.

1.	Index Codes Building/Type: SSC ID: Site Area:
2.	Quality Level and Determination #: 1 QL Determination # 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 148B will run at a total core power of 106 MW for a nominal 53 days The physics analysis contained herein was performed using a total core power of 104 MW with a fuel loading for 53 days. Attached are the reactor physics data in support of the ATR Core Safety Assurance Program for Cycle 148B. The results of the calculation show that none of the SAR/TSR limits will be violated during cycle 148B when in 2-PCP operation.

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

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Requester	Ac		
Nuclear Safety[3]	Ac	N.A.	
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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.
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CONTENTS

APPENDIXES

Attachment 1 – Results of Reactor Physics Safety Analysis for Advanced Test Reactor (ATR) Cycle 148B

SCOPE AND BRIEF DESCRIPTION

See above.

DESIGN OR TECHNICAL PARAMETER INPUT AND SOURCES

1. Quality level source: QL Determination # RTC-000088
2. 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.
3. 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 attachment.

COMPUTER CODE VALIDATION

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

Title: Results of Reactor Physics Safety Analysis for Advanced Test Reactor (ATR) Cycle 148B

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DISCUSSION/ANALYSIS

See attachment.

RECOMMENDATIONS

See attachment.

PE STAMP

N.A.

REFERENCES

See attachment.

Attachment

Results of Reactor Physics Safety Analysis for Advanced Test Reactor (ATR) Cycle 148B

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 148B was run for 53 days (Ref. 5) using a nominal lobe power (MW) division of 18-18-23-22-23 (NW-NE-CR-SW-SE) for a total reactor power of 104 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 148B fuel charge consists of the following fuel elements:

13 New 7F elements	17 recycle 7F elements
2 New NB elements	4 recycle NB elements
0 New YA elements	0 recycle YA elements
0 New YA...M elements	4 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. By the end of reactor cycle 147A, the exposure of the reflector adjacent to the SW and SE lobes had passed the level where the ligament A stress exceeded 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 148B. 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), and modified in Reference 11, 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.

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	362	385	F-32	5	100	0	222
NE	362	385	F-9	5	100	0	204
CR	362	385	F-21	5	100	3	251
SW	362	385	F-22	5	100	0	247
SE	362	385	F-19	5	100	0	232

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	362	385	F-32	5	100	0	222
NE	362	385	F-1,10	5	100	3,17	205
SW	362	385	F-21	5	100	3	251
SE	362	385	F-20	5	100	3	250

Table 3 shows the limits for the EPP as specified in ATR Technical Safety Requirements 3.6.1(a) (Table 3.6.1-1), and modified in Reference 11, 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	362	387	F-33	19	100	0	150
NE	362	387	F-8	19	100	0	162
CR	362	387	F-10	19	100	3,10, 17	158
SW	362	387	F-23	19	100	0	218
SE	362	387	F-18	19	100	0	207

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 148B 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 148B Most Limiting EPP
19	362	23	19	100	0	218
Inner	362	22	5	100	0	247
19	362	23	19	100	3	196
Inner	362	21	5	100	3	251
19	362	23	19	100	10	194
Inner	362	21	5	100	10	236
19	362	23	19	100	17	192
Inner	362	21	5	100	17	223
19	362	23	19	100	24	189
Inner	362	21	5	100	24	225
19	362	23	19	100	31	187
Inner	362	21	5	100	31	228
19	362	23	19	100	38	184
Inner	362	21	5	100	38	227
19	362	23	19	100	45	183
Inner	362	22	5	100	45	229
19	362	23	19	100	52	177
Inner	362	22	5	100	52	224
19	362	23	19	100	53	174
Inner	362	22	5	100	53	219

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), and modified in Reference 11 must be used. The most limiting EPP values for these positions are given below along with the <2σ limits.

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 148B 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	353	374	174	24	15	3	100
SW/Plate 19	311	310	151	24	19	3	100
SE/Inner Plates	353	374	180	17	15	3,52,53	100
SE/Plate 19	311	310	169	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 $x10^{21}$ limit at each time step.

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

Days	Position Numbers
0	
3	
10	10
17	10, 40
24	1,10, 30,31, 40
31	1,10,15,20,21,25,30,31,40
38	1,10,11,15,20,21,25,30,31,40
45	1,10,11,15,20,21,24,25,26,27,30,31,37,40
52	1,10,11,15,16,20,21,24,25,26,27,28,30,31,33,37,38,40
53	1,10,11,15,16,20,21,24,25,26,27,28,30,31,33,34,37,38,40

Once an element has reached 1.5 x 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 x 10^{21} fission density during the cycle.

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

Lobe	Effective Point Power Limit		Cycle 148B Most Limiting Effective Point Power By Lobe				
	2 PCP	3 PCP	Pos.	Plate	Restricted to (%) of limit	Days	EPP
NW	446	465	F-33	15	100	52	184
NE	446	465	NA	NA	100	NA	NA
CR	446	465	F-21	5	100	31	278
SW	435	453	F-24	15	100	45	198
SE	435	453	F-15	15	100	31	177

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

Lobe	Effective Point Power Limit		Cycle 148B Most Limiting Effective Point Power By Lobe				
	2 PCP	3 PCP	Pos.	Plate	Restricted to (%) of limit	Days	EPP
NW	411	428	F-33	19	100	52	149
NE	411	428	NA	19	100	NA	NA
CR	411	428	F-10	19	100	10	196
SW	411	428	F-24	19	100	45	150
SE	411	428	F-15	19	100	31	141

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	25.77	All, inner plates	194	F-32	5	1.00	659/1.45 = 454	60.3*
			All, plate 19	168	F-38	19	1.00	659/1.45 = 454	69.6
NE	19.5	26.04	All, inner plates	204	F-9	5	1.00	659/1.45 = 454	57.9*
			All, plate 19	188	F-8	19	1.00	659/1.45 = 454	62.8
C	30.0	31.20	All, inner plates	234	F-21	15	1.00	659/1.45 = 454	60.5*
			All, plate 19	163	F-10	19	1.00	659/1.45 = 454	86.9
SW	26.0	34.72	All, inner plates	259	F-23	15	1.00	659/1.45 = 454	60.8
			All, plate 19	247	F-23	19	1.00	659/1.45 = 454	63.8
			< 2 sigma, inner plates	242	F-24	15	1.00	641/1.45 = 442	63.4
			< 2 sigma, plate 19	223	F-24	19	1.00	490/1.37 = 357	55.5*
SE	26.0	34.78	All, inner plates	256	F-17	15	1.00	659/1.45 = 454	61.6
			All, plate 19	254	F-17	19	1.00	659/1.45 = 454	62.1
			< 2 sigma, inner plates	256	F-17	15	1.00	641/1.45 = 442	60.0
			< 2 sigma, plate 19	254	F-17	19	1.00	490/1.37 = 357	48.8*

* 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 setpoint. 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 148B is 4.17 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 2.55 in position F-23 for the time step 0.

The preliminary startup power division normalized to a total core power of 250 MW is: 37.4-37.2-58.3-58.2-58.9(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	948	52.6	1934	92.0
NE	1097	60.9	1916	98.2
C	---	---	1653	55.1
SW	1538	69.9	1896	72.9
SE	1633	71.0	1998	76.8

a. The reactivity estimates were obtained using the XSPRJ method.
b. The Time in Cycle is based on the nominal power division of 18-18-23-22-23 (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 53 days except for the NW Lobe. PDQ typically underestimates the reactivity in the NW lobe by approximately 0.50$, so this should not be a problem. The results also show that the fission density limits should not be exceeded for a cycle length of 53 days. The maximum center lobe power for the cycle is set at 27 MW (Ref. 6) which would change the time in the cycle required to reach the fission density limit in the center lobe to 49.81 days. Therefore the fission density limit should not be exceeded for 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 148B are expected to have further recycle potential after the nominal operation of Cycle 148B except for the following:

Pos.	Serial No.
10	XA737T

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 12 and 13.

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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Table A1. Experimental Designations and Nominal Power Division for ATR Cycle 148B[5,6]

Lobe	Power	Loop Experiments
NW	18^{+3}_{-3}	2E/NW-100 R#1
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-74 Lo. Corr. R#0
C	25^{+3}_{-5}	7-Pin Flux Trap Irradiation Facility with one LSA Cobalt and Aluminum Fillers
E	-	7-Pin Flux Trap Irradiation Facility with AFCI in E1-E2, GFR-F1-2 in E3, UW-2 in E4, Drex-A in E5, and Aluminum Fillers in E6 and E7
SW	22^{+4}_{-2}	2D/SW-184 STD R#3
S	-	AGC-1
SE	23^{+3}_{-3}	2B/SE-191 STD BU R#1

Table A2. Summary of Fuel Load for Cycle 148B

Core	Serial	Content		Total	Irradiation History							
Pos.	No.	^{235}U	^{10}B	MWD	Cycle	Pos.	Cycle	Pos.	Cycle	Pos.	Cycle	Pos.
1	XA583T	822	0.099	1678	138A-1	3	140B-1	5				
2	XA225T	1075	0.660									
3	XA226T	1075	0.660									
4	XA743TNB	931	0.000	787	144A-1	3						
5	XA632TNB	909	0.000	707	146B-1	9						
6	XA884T	920	0.211	1021	146B-1	14						
7	XA228T	1075	0.660									
8	XA229T	1075	0.660									
9	XA762TNB	1075	0.000									
10	XA737T	808	0.094	1544	143B-1	29						
11	YA523TM	843	0.123	1299	142B-1	16						
12	XA241T	1075	0.660									
13	XA243T	1075	0.660									
14	XA846T	965	0.303	907	146A-1	5						
15	XA796T	867	0.147	1093	144A-1	19						
16	XA898T	919	0.210	1157	147A-1	35						
17	XA244T	1075	0.660									
18	XA851T	1075	0.660									
19	XA852T	1075	0.660									
20	YA533TM	843	0.123	1315	143A-1	26						
21	YA541TM	845	0.126	1191	144B-1	27						
22	XA233T	1075	0.660									
23	XA237T	1075	0.660									
24	XA858T	946	0.263	904	146B-1	34						
25	XA890T	880	0.167	1021	146B-1	19						
26	XA908T	888	0.163	1049	147A-1	28						
27	XA857T	916	0.202	904	146B-1	33						
28	XA860T	944	0.260	904	146B-1	37						
29	XA240T	1075	0.660									
30	YA465TM	836	0.115	1186	139A-1	24						
31	XA685T	836	0.104	1628	141A-1	23	143A-1	5				
32	XA760TNB	1075	0.000									
33	XA868T	915	0.200	903	146B-1	28						
34	XA899T	903	0.187	1157	147A-1	37						
35	XA625TNB	895	0.000	981	145A-1	3						
36	XA889T	890	0.161	1021	146B-1	18						
37	XA626TNB	896	0.000	981	145A-1	8						
38	XA885T	914	0.200	1021	146B-1	17						
39	XA224T	1075	0.660									
40	XA273T	818	0.101	1475	128A-1	12						

Table A3. Plate Restrictions for Fuel Loaded in Cycle 148B[9,10]

Core Pos.	Serial No.	Restriction	Restricted Plates (of those represented in the PDQ model)			
1	XA583T					
2	XA225T					
3	XA226T					
4	XA743TNB					
5	XA632TNB					
6	XA884T					
7	XA228T					
8	XA229T					
9	XA762TNB					
10	XA737T					
11	YA523TM					
12	XA241T					
13	XA243T					
14	XA846T					
15	XA796T					
16	XA898T					
17	XA244T					
18	XA851T					
19	XA852T					
20	YA533TM					
21	YA541TM					
22	XA233T					
23	XA237T					
24	XA858T					
25	XA890T					
26	XA908T					
27	XA857T					
28	XA860T					
29	XA240T					
30	YA465TM					
31	XA685T					
32	XA760TNB					
33	XA868T					
34	XA899T					
35	XA625TNB					
36	XA889T					
37	XA626TNB					
38	XA885T					
39	XA224T					
40	XA273T	0.96	15	18	19	0

Table A4. Capsule Facility Loading Used in ATR Cycle 148B Analysis[5]

Facility	Description	Reference
C-1	Aluminum Filler	
C-2	Aluminum Filler	
C-3	Aluminum Filler	
C-4	Aluminum Filler	
C-5	Aluminum Filler	
C-6	Aluminum Filler	
C-7	LSA Cobalt	
E-1	AFC-2D	KEB-06-10, Rev. 2
E-2	AFC-2E	KEB-06-10, Rev. 2
E-3	GFR-F1-2	KEB-06-10, Rev. 2
E-4	UW-2	KEB-06-10, Rev. 2
E-5	Drex-A	KEB-06-10, Rev. 2
E-6	Aluminum Filler	KEB-06-10, Rev. 2
E-7	Aluminum Filler	KEB-06-10, Rev. 2
SFT	AGC-1	MED-01-09
A-1	HSA Cobalt	BJH-2-92
A-2	HSA Cobalt	BJH-2-92
A-3	HSA Cobalt	BJH-2-92
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	HSA Cobalt	RAK-04-02
A-11	UI-1-7	GWW-06-10
A-12	SFROP	
A-13	Long SFR	
A-14	Long SFR	
A-15	Long SFR	
A-16	Long SFR	
B-1	YSFR	
B-2	YSFR	
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 Hardware	Dwg # 600271

Table A4. Continued

Facility	Description	Reference
B-8	YSFR	
B-9	Aluminum Filler	
B-10	Aluminum Filler	
B-11	Aluminum Filler	
B-12	AGR-2	SBG-01-10
H-1	HSA Cobalt	TMS-06-08
H-2	HSA Cobalt	TMS-06-08
H-3	N-16 MONITOR	
H-4	HSA Cobalt	TMS-06-08
H-5	HSA Cobalt	TMS-06-08
H-6	HSA Cobalt	TMS-06-08
H-7	HSA Cobalt	TMS-06-08
H-8	HSA Cobalt	TMS-06-08
H-9	Gadolinium	DJL-02-10
H-10	HSA Cobalt	TMS-06-08
H-11	N-16 MONITOR	
H-12	HSA Cobalt	TMS-06-08
H-13	HSA Cobalt	TMS-06-08
H-14	HSA Cobalt	TMS-06-08
H-15	HSA Cobalt	TMS-06-08
H-16	HSA Cobalt	TMS-06-08
I-1 through I-20	Beryllium Filler	
I-21 through I-24	Aluminum Filler	

Table A5. Summary of ATR Shim Positions for ATR Cycle 148B

(from PQMAP.OUT)

	NW LOBE		NE LOBE		SW LOBE		SE LOBE	
Time At Power (Days)	**Outer Shims (Deg.)**	**Neck Shims Inserted**	**Outer Shims (Deg.)**	**Neck Shims Inserted**	**Outer Shims (Deg.)**	**Neck Shims Inserted**	**Outer Shims (Deg.)**	**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	64.7	1 2 3 4 5 6	69.7	1 2 3 4 5 6	51.2	1 2 3 5 6	56.6	1 2 3 5 6
3	85.4	1 2 3 4	85.4	1 2 3	85.4	1 2 3 5 6	85.4	1 2 3 5 6
10	85.4	1 2	85.4	1	85.4	1 2 3 5 6	85.4	1 2 3 5 6
17	85.4		85.4		85.4	1 2 3 5 6	85.4	1 2 3 5 6
24	89.8		89.8		85.4	1 2 3 5	85.4	1 2 3 5
31	89.8		89.8		85.4	1 2 3	85.4	1 2 3
38	89.8		89.8		85.4	1 2	85.4	1 2
45	100.1		100.1		85.4		89.8	
52	111.7		100.1		89.8		95.2	
53	116.4		104.2		95.2		95.2	

Table A6. Summary of ATR Core Power and Calculated $K_{effective}$ for ATR Cycle 148B (from PQMAP.OUT)

Time at Power (Days)	**Total Core Power (MW)**	**Lobe Powers (MW)** NW	NE	CR	SW	SE	$K_{effective}$
0	104	15.6	15.5	24.2	24.2	24.5	0.9890
0	104	16.5	17.4	24.0	22.2	24.0	0.9904
3	104	16.8	16.9	22.0	24.1	24.1	0.9919
10	104	17.5	17.6	22.6	23.0	23.2	0.9955
17	104	17.9	17.9	23.3	22.3	22.6	0.9976
24	104	17.7	17.9	23.0	22.5	23.1	0.9987
31	104	17.0	17.4	22.9	22.9	23.8	0.9988
38	104	16.6	17.2	23.1	23.1	24.1	0.9972
45	104	16.5	17.4	23.5	22.4	24.2	1.0040
52	104	17.0	17.1	23.0	22.5	24.5	0.9998
53	104	17.1	17.2	22.7	22.9	24.1	1.0010

Table A7. Summary of ATR Shim Positions for ATR Cycle 148B 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 0 0	85.4	1 1 1 0 0 0	85.4	1 1 1 0 1 1	0.0	1 1 1 0 1 1
NE	85.4	1 1 1 1 0 0	153.9	1 1 1 0 0 0	0.0	1 1 1 0 1 1	85.4	1 1 1 0 1 1
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 0 0	0.0	1 1 1 0 0 0	153.9	1 1 1 0 1 1	85.4	1 1 1 0 1 1
SE	0.0	1 1 1 1 0 0	85.4	1 1 1 0 0 0	85.4	1 1 1 0 1 1	153.9	1 1 1 0 1 1

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

	Total Core Power	Lobe Powers (MW)					
Lobe	**(MW)**	**NW**	**NE**	**CR**	**SW**	**SE**	**$K_{effective}$**
NW	104	25.77	17.56	22.31	24.95	13.41	0.986544
NE	104	17.29	26.04	22.31	13.23	25.12	0.986892
CR	104	15.68	15.62	31.20	20.76	20.74	0.983405
SW	104	15.53	9.66	21.29	34.72	22.80	1.001671
SE	104	9.34	15.95	21.28	22.65	34.78	1.002085

Table A9. Summary of Fuel Element Powers for ATR Cycle 148B [redacted]

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	104	2.6	2.5	2.1	1.6	1.3	1.3	1.6	2.3	2.8	2.8
0	104	2.7	2.6	2.4	1.8	1.6	1.6	1.9	2.5	2.9	2.9
3	104	2.5	2.6	2.3	1.8	1.6	1.6	1.8	2.3	2.9	2.7
10	104	2.8	2.8	2.4	1.9	1.7	1.6	1.9	2.4	3.0	2.9
17	104	3.0	2.9	2.4	1.9	1.7	1.6	1.9	2.4	3.0	3.0
24	104	2.9	2.8	2.4	1.9	1.7	1.7	1.9	2.4	3.0	2.9
31	104	2.8	2.8	2.3	1.8	1.6	1.6	1.9	2.4	2.9	2.9
38	104	2.8	2.7	2.3	1.8	1.6	1.6	1.9	2.4	2.9	2.9
45	104	2.7	2.7	2.3	1.8	1.7	1.7	1.9	2.4	2.8	2.8
52	104	2.6	2.6	2.3	1.8	1.7	1.7	1.9	2.4	2.8	2.8
53	104	2.6	2.6	2.3	1.8	1.7	1.7	1.9	2.4	2.8	2.7

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	104	3.1	3.4	3.3	2.7	2.3	2.4	3.0	3.6	3.8	3.5
0	104	3.1	3.4	3.2	2.7	2.2	2.3	2.9	3.5	3.7	3.4
3	104	2.8	3.1	3.1	2.8	2.7	2.7	3.0	3.4	3.3	3.0
10	104	2.8	3.0	3.0	2.7	2.5	2.6	2.9	3.3	3.2	2.9
17	104	2.8	3.0	3.0	2.6	2.4	2.5	2.8	3.2	3.2	2.9
24	104	2.8	3.1	3.0	2.7	2.4	2.5	2.8	3.3	3.3	2.9
31	104	2.8	3.2	3.1	2.7	2.5	2.5	2.9	3.4	3.5	3.0
38	104	2.9	3.3	3.1	2.7	2.5	2.6	3.0	3.4	3.6	3.1
45	104	3.1	3.4	3.1	2.7	2.5	2.6	3.0	3.4	3.6	3.3
52	104	3.0	3.3	3.1	2.8	2.5	2.6	3.0	3.4	3.6	3.2
53	104	2.9	3.3	3.1	2.7	2.5	2.6	3.0	3.4	3.5	3.2

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	104	3.5	3.8	3.6	2.9	2.3	2.3	2.7	3.1	3.5	3.1
0	104	3.4	3.6	3.3	2.6	2.0	2.0	2.4	2.9	3.3	3.0
3	104	3.1	3.3	3.5	3.0	2.7	2.7	2.8	3.1	3.1	2.8
10	104	3.0	3.2	3.3	2.8	2.6	2.5	2.7	2.9	3.0	2.7
17	104	2.9	3.1	3.2	2.7	2.4	2.4	2.6	2.9	3.0	2.8
24	104	2.9	3.2	3.2	2.7	2.4	2.4	2.6	2.9	3.1	2.7
31	104	3.0	3.4	3.3	2.7	2.4	2.4	2.6	2.9	3.2	2.8
38	104	3.1	3.5	3.4	2.7	2.4	2.4	2.6	2.9	3.3	2.8
45	104	3.3	3.5	3.3	2.6	2.3	2.3	2.4	2.8	3.3	3.0
52	104	3.2	3.5	3.3	2.6	2.3	2.3	2.4	2.8	3.2	2.9
53	104	3.2	3.5	3.3	2.7	2.4	2.4	2.5	2.8	3.2	2.9

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	104	2.9	2.9	2.3	1.6	1.3	1.2	1.6	2.1	2.6	2.6
0	104	2.9	2.9	2.3	1.7	1.4	1.4	1.8	2.3	2.7	2.7
3	104	2.7	2.8	2.3	1.8	1.6	1.6	1.8	2.2	2.6	2.5
10	104	2.8	2.9	2.4	1.8	1.7	1.7	1.9	2.4	2.8	2.7
17	104	3.0	3.0	2.4	1.9	1.7	1.7	1.9	2.4	3.0	3.0
24	104	2.9	3.0	2.3	1.8	1.7	1.7	1.9	2.4	2.9	2.9
31	104	2.9	2.9	2.3	1.8	1.6	1.6	1.8	2.3	2.8	2.8
38	104	2.8	2.8	2.2	1.7	1.6	1.5	1.8	2.2	2.8	2.7
45	104	2.8	2.8	2.2	1.7	1.6	1.6	1.8	2.2	2.7	2.7
52	104	2.7	2.7	2.2	1.8	1.7	1.7	1.9	2.2	2.7	2.6
53	104	2.7	2.7	2.2	1.9	1.7	1.7	1.9	2.2	2.7	2.6

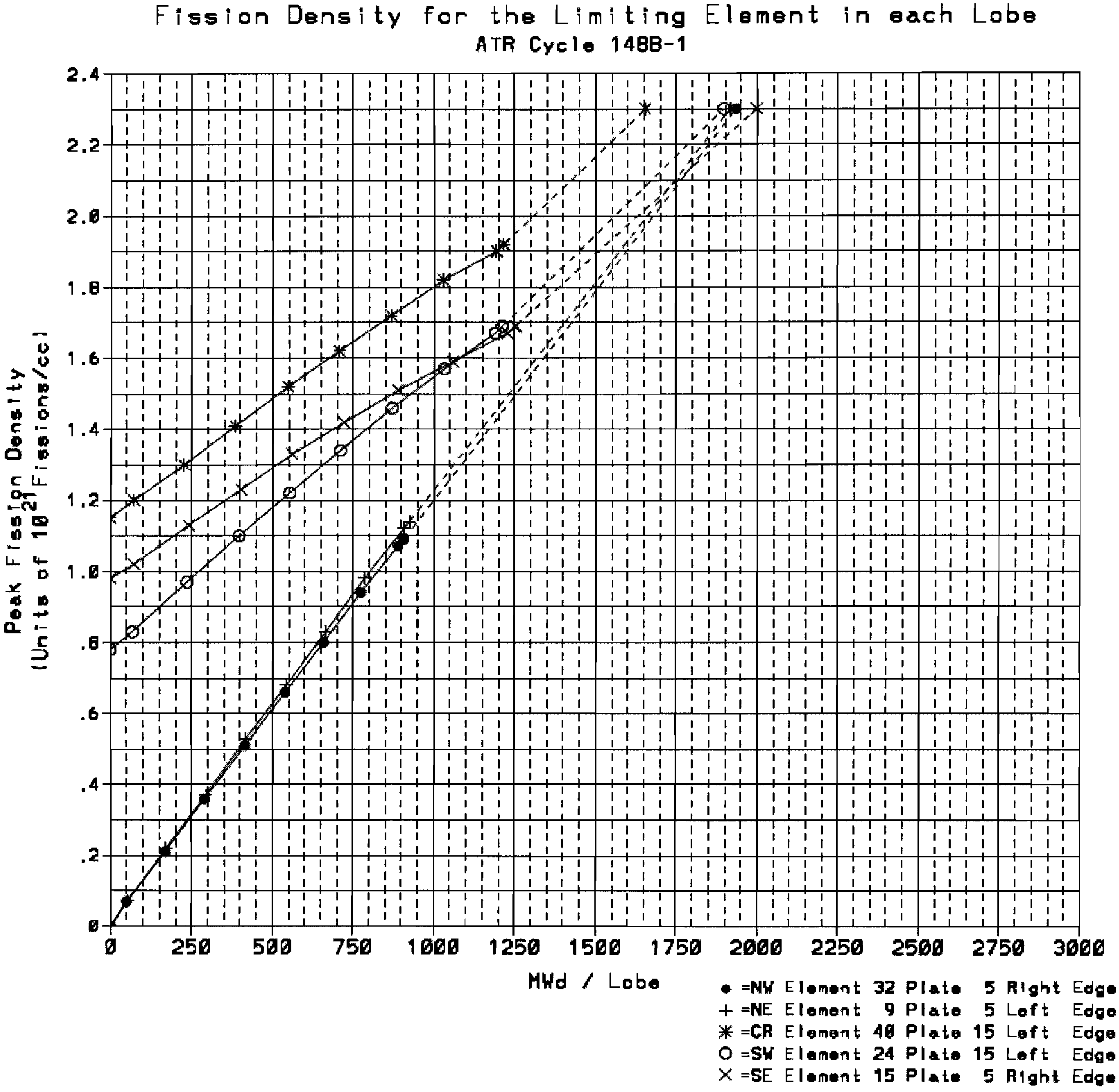

Figure A1. Fission Density for the Limiting Element in each Lobe For Cycle 148B-1

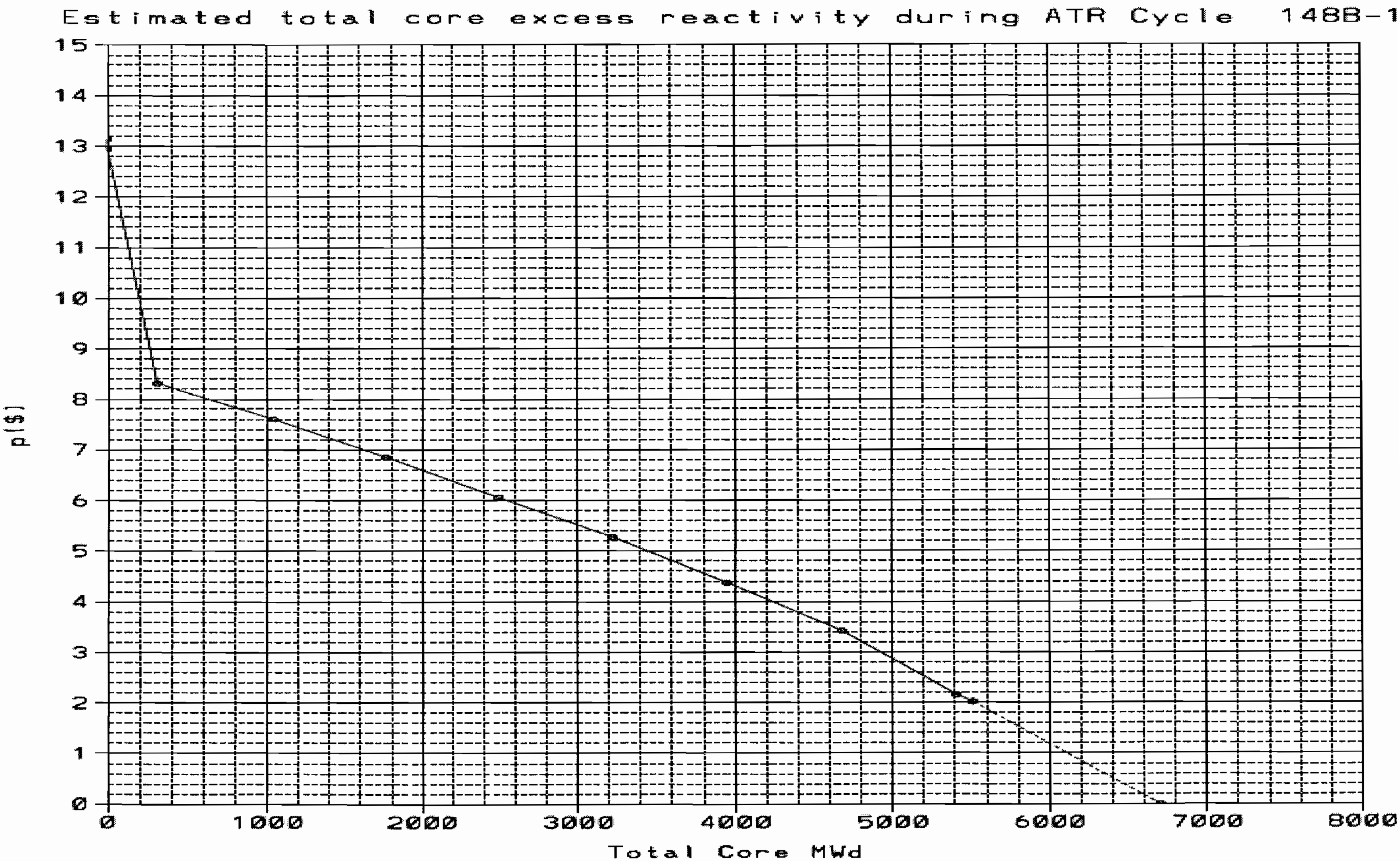

Figure A2. Estimated Total Core Excess Reactivity During ATR Cycle 148B-1