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ECAR-1400Results Of Reactor Physics Safety Analysis For Advanced Test Reactor (ATR) Cycle 149A With NW-160 IN NW Lobe

December 2010

Changing the World's Energy Future

Mitchell A Plummer

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 149A WITH NW-160 IN NW LOBE

ECAR No.: 1400 ECAR Rev. No.: 0 Project File No.: Date: 02/28/2011

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 149A will run at a total core power of 109 MW for a nominal 49 days. Attached are the reactor physics data in support of the ATR Core Safety Assurance Program for Cycle 149A. The physics analysis contained herein was performed using a total core power of 105 MW with a fuel loading for 49 days. The results of the calculation show that none of the SAR/TSR limits will be violated during cycle 149A 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		P. A. Roth/W321/GB20	P. A. Roth 2/25/11
Data Verifier	R	C. C. McKenzie/W321/GB20	[signature] for C.C. McKenzie per telecon 2/28/11
Technical Checker	R	A. W. LaPorta/W321/GB20	Pages checked: All [signature] 2/28/11
Independent Peer Reviewer[3]	R	N/A	
Performer's Manager	A	J. C. Chapman/W321/GB25	[signature] for J.C. Chapman 2/28/11
Requester	Ac		
Nuclear Safety[3]	Ac	N/A	
CUI Review		C. J. Stanley /W432	C. J. Stanley 2/28/11
Doc Control		Michele Robb	Michele Robb 3/2/11

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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Appendix A – Results of Reactor Physics Safety Analysis for Advanced Test Reactor (ATR) Cycle 149A with NW-160 in NW Lobe

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 149A with NW-160 in NW Lobe

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 149A was run for 49 days (Ref. 5) using a nominal lobe power (MW) division of 18-18-23-23-23 (NW-NE-CR-SW-SE) for a total reactor power of 105 MW. Effective plate power (EPP) values have been computed using maximum lobe powers (MW) of 21-19.5-29-26-26 (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 149A fuel charge consists of the following fuel elements:

14 New 7F elements	16 recycle 7F elements
2 New NB elements	3 recycle NB elements
0 New YA elements	0 recycle YA elements
0 New YA...M elements	5 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 149A. 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	230
NE	362	385	F-9	5	100	0	221
CR	362	385	F-21	5	100	3	238
SW	362	385	F-22	5	100	0	245
SE	362	385	F-19	5	100	0	246

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	230
NE	362	385	F-9	5	100	0	221
SW	362	385	F-22	5	100	0	245
SE	362	385	F-19	5	100	0	246

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-32	19	100	24	153
NE	362	387	F-8	19	100	0	170
CR	362	387	F-30	19	100	3	148
SW	362	387	F-23	19	100	0	214
SE	362	387	F-18	19	100	0	214

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 149A 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 149A Most Limiting EPP
19	362	18,23	19	100	0	214
Inner	362	19	5	100	0	246
19	362	23	19	100	3	198
Inner	362	21	5	100	3	238
19	362	23	19	100	10	195
Inner	362	21	5	100	10	231
19	362	18,23	19	100	17	190
Inner	362	21	5	100	17	231
19	362	18	19	100	24	187
Inner	362	21	5	100	24	223
19	362	18	19	100	31	184
Inner	362	21	5	100	31	220
19	362	18,23	19	100	38	179
Inner	362	19,21	5	100	38	216
19	362	18,23	19	100	45	175
Inner	362	19	5	100	45	219
19	362	23	19	100	49	173
Inner	362	22	5	100	49	217

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 $<2\sigma$ limits.

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

Lobe/Plate	**Effective Plate Power Limit**		**Cycle 149A Most Limiting EPP for Ligament A ($<2\sigma$) Positions By Lobe**				
	2 PCP	**3 PCP**	**EPP**	**Pos.**	**Plate**	**Days**	**Restricted to (%) of limit**
SW/Inner Plates	353	374	180	24	15	17,24	100
SW/Plate 19	311	310	164	24	19	17	100
SE/Inner Plates	353	374	173	17	15	3	100
SE/Plate 19	311	310	151	17	19	3	100

The elements in several positions of the fuel loading for this cycle, reach a fission density greater than $1.5x10^{21}$ 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	37
10	10,37,40
17	1,10,37,40
24	1,5,10,30,31,36,37,38,40
31	1,5,10,15,21,30,31,35,36,37,38,40
38	1,5,10,11,14,15,17,20,21,30,31,33,34,35,36,37,38,40
45	1,5,6,10,11,14,15,16,17,20,21,25,26,30,31,33,34,35,36,37,38,40
49	1,5,6,10,11,14,15,16,17,20,21,25,26,30,31,33,34,35,36,37,38,40

Once an element exceeds 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 149A Most Limiting Effective Point Power By Lobe				
	2 PCP	3 PCP	Pos.	Plate	Restricted to (%) of limit	Days	EPtP
NW	446	465	F-38	15	100	24	211
NE	446	465	F-6	15	100	45,49	121
CR	446	465	F-21	5	100	31	268
SW	435	453	F-26	15	100	45	172
SE	435	453	F-17	15	100	38	197

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 149A Most Limiting Effective Point Power By Lobe				
	2 PCP	3 PCP	Pos.	Plate	Restricted to (%) of limit	Days	EPtP
NW	411	428	F-38	19	100	24	181
NE	411	428	F-6	19	100	45,49	97
CR	411	428	F-1	19	100	17	181
SW	411	428	F-26	19	100	45	130
SE	411	428	F-17	19	100	38	154

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	26.87	All, inner plates	211	F-32	5	1.00	659/1.45 = 454	57.8*
			All, plate 19	167	F-38	19	1.00	659/1.45 = 454	73.0
NE	19.5	27.75	All, inner plates	217	F-9	5	1.00	659/1.45 = 454	58.0*
			All, plate 19	206	F-8	19	1.00	659/1.45 = 454	61.1
C	29.0	31.64	All, inner plates	239	F-20	15	1.00	659/1.45 = 454	60.1*
			All, plate 19	160	F-30	19	1.00	659/1.45 = 454	89.7
SW	26.0	42.48	All, inner plates	319	F-24	15	1.00	659/1.45 = 454	60.4
			All, plate 19	302	F-24	19	1.00	659/1.45 = 454	63.8
			< 2 sigma, inner plates	319	F-24	15	1.00	641/1.45 = 442	58.8
			< 2 sigma, plate 19	302	F-24	19	1.00	490/1.37 = 357	50.2*
SE	26.0	41.05	All, inner plates	301	F-18	15	1.00	659/1.45 = 454	61.9
			All, plate 19	276	F-18	19	1.00	659/1.45 = 454	67.5
			< 2 sigma, inner plates	286	F-16	15	1.00	641/1.45 = 442	63.4
			< 2 sigma, plate 19	253	F-17	19	1.00	490/1.37 = 357	57.9*

* 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 149A is 4.06 MW in core position F-20.

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 2.59 in position F-23 for the time step 0.

The preliminary startup power division normalized to a total core power of 250 MW is: 36.3-36.2-60.6-59.6-57.3(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	871	48.3	1411	67.1
NE	1021	56.7	1884	96.6
C	---	---	1724	59.4
SW	1864	81.0	2225	85.5
SE	1559	67.7	2044	78.6

a. The reactivity estimates were obtained using the XSPRJ method.
b. The Time in Cycle is based on the nominal power division of 18-18-23-23-23 (NW-NE-CR-SW-SE).
c. The Time in Cycle is based on the maximum power division of 21-19.5-29-26-26 (NW-NE-CR-SW-SE).

The results above show sufficient reactivity to sustain the requested lobe power for the cycle length of 49 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 49 days. The reactivity and fission density data are shown in Figures A1 and A2.
All of the elements in the fuel loading for Cycle 149A are expected to have further recycle potential after the nominal operation of Cycle 149A.

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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11. S. T. Polkinghorne, Interim Power Limits for ATR Fuel Plates, EDF-7420, October 2006.
12. P. A. Roth, Verification and Validation of ATR Physics Analysis Software on Workstation Castalia, ECAR-516, February, 2009.
13. 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 149A[5,6]

Lobe	Power	Loop Experiments
NW	18^{+3}_{-3}	2E/NW-160 R#2
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	23^{+6}_{-2}	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-E7
SW	23^{+3}_{-3}	2D/SW-184 STD R#3
S	-	AGC-2
SE	23^{+3}_{-3}	2B/SE-191 STD BU R#1

Table A2. Summary of Fuel Load for Cycle 149A

Core Pos.	Serial No.	Content ^{235}U	Content ^{10}B	Total MWD	Irradiation History Cycle	Pos.	Cycle	Pos.	Cycle	Pos.	Cycle	Pos.
1	XA696T	837	0.116	1197	142B-1	39						
2	XA863T	1075	0.660									
3	XA892T	1075	0.660									
4	XA877T	954	0.282	856	148A-1	7						
5	XA613TNB	839	0.000	1516	141A-1	8	144B-1	7				
6	XA614TNB	847	0.000	1105	142A-1	32						
7	XA866T	946	0.257	707	146B-1	3						
8	XA894T	1075	0.660									
9	XA764TNB	1075	0.000									
10	XA399T	797	0.074	1850	137B-1	24	138B-1	15				
11	YA535TM	853	0.134	1223	143A-1	16						
12	XA904T	1075	0.660									
13	XA911T	1075	0.660									
14	XA903T	908	0.192	904	147A-1	3						
15	YA534TM	857	0.138	1223	143A-1	15						
16	XA880T	921	0.212	856	148A-1	33						
17	XA869T	907	0.190	1094	148A-1	14						
18	XA915T	1075	0.660									
19	XA916T	1075	0.660									
20	YA470TM	852	0.132	1186	139A-1	25						
21	YA507TM	856	0.146	1197	142B-1	37						
22	XA917T	1075	0.660									
23	XA919T	1075	0.660									
24	XA920T	1075	0.660									
25	XA888T	895	0.171	1044	148A-1	28						
26	XA881T	918	0.208	856	148A-1	38						
27	XA921T	1075	0.660									
28	XA922T	1075	0.660									
29	XA923T	1075	0.660									
30	XA714T	845	0.111	1323	142B-1	28						
31	XA713T	837	0.101	1323	142B-1	23						
32	XA767TNB	1075	0.000									
33	XA910T	864	0.149	1155	147A-1	12						
34	YA476TM	859	0.140	1165	134B-1	15						
35	XA712T	831	0.117	1323	142B-1	22						
36	XA738T	818	0.099	1435	143B-1	12						
37	XA122T	780	0.062	1818	131A-1	23	136B-1	35				
38	XA759TNB	849	0.000	1020	145B-1	9						
39	XA896T	1075	0.660									
40	XA755R	822	0.108	1324	124A-1	22						

Table A3. Plate Restrictions for Fuel Loaded in Cycle 149A[9,10]

Core Pos.	Serial No.	Restriction	Restricted Plates (of those represented in the PDQ model)
1	XA696T		
2	XA863T		
3	XA892T		
4	XA877T		
5	XA613TNB		
6	XA614TNB		
7	XA866T		
8	XA894T		
9	XA764TNB		
10	XA399T		
11	YA535TM		
12	XA904T		
13	XA911T		
14	XA903T		
15	YA534TM		
16	XA880T		
17	XA869T		
18	XA915T		
19	XA916T		
20	YA470TM		
21	YA507TM		
22	XA917T		
23	XA919T		
24	XA920T		
25	XA888T		
26	XA881T		
27	XA921T		
28	XA922T		
29	XA923T		
30	XA714T		
31	XA713T		
32	XA767TNB		
33	XA910T		
34	YA476TM		
35	XA712T		
36	XA738T		
37	XA122T		
38	XA759TNB		
39	XA896T		
40	XA755R		

Table A4. Capsule Facility Loading Used in ATR Cycle 149A 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	BJH-08-93
E-1	AFC-2D	KEB-07-10
E-2	AFC-2E	KEB-07-10
E-3	GFR-F1-2	KEB-07-10
E-4	UW-2	KEB-07-10
E-5	Drex-A	KEB-07-10
E-6	Aluminum Filler	KEB-07-10
E-7	Aluminum Filler	KEB-07-10
SFT	AGC-2	MED-01-11
A-1	HSA Cobalt	BJH-2-92
A-2	HSA Cobalt	BJH-2-92
A-3	Drex-B	Drex20100212
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	HSA Cobalt	RAK-04-02
A-12	SFROP	
A-13	EPRI –ZG-D	GWW-03-11
A-14	EPRI –ZG-B	GWW-03-11
A-15	Long SFR	
A-16	EPRI –ZG-A	GWW-03-11
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 (UI and Drexel shuttles)	GWW-01-11, GWW-02-11

Table A4. Continued

Facility	Description	Reference
B-8	YSFR	
B-9	Aluminum Filler	
B-10	RERTR-13-1	GNH-02-10
B-11	RERTR-12-3	GNH-01-11
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	HSA Cobalt	TMS-06-08
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 thru I-20	Beryllium Filler	
I-21 & I-22	Aluminum Filler	
I-23	LWRS-1	KEB-08-10
I-24	Aluminum Filler	

Table A5. Summary of ATR Shim Positions for ATR Cycle 149A

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	51.2	1 2 3 4 5 6	51.2	1 2 3 4 5 6	51.2	1 2 3 5 6	51.2	1 2 3 5 6
0	64.7	1 2 3 4 5 6	61.0	1 2 3 4 5 6	46.5	1 2 3 5 6	51.2	1 2 3 5 6
3	85.4	1 2 3	85.4	1 2 3	79.3	1 2 3 5 6	85.4	1 2 3 5 6
10	85.4	1 2	85.4	1 2	79.3	1 2 3 5 6	85.4	1 2 3 5 6
17	85.4	1	85.4	1 2	85.4	1 2 3 5 6	85.4	1 2 3 5
24	85.4		85.4	1	85.4	1 2 3 5 6	85.4	1 2 3 5
31	89.8		85.4		85.4	1 2 3 5	85.4	1 2 3
38	100.1		89.8		85.4	1 2 3 5	85.4	1 2
45	111.7		95.2		85.4	1 2	89.8	
49	116.4		100.1		85.4	1	95.2	

Table A6. Summary of ATR Core Power and Calculated $K_{effective}$ for ATR Cycle 149A

Time at Power (Days)	Total Core Power (MW)	Lobe Powers (MW) NW	NE	CR	SW	SE	$K_{effective}$
0	105	15.2	15.2	25.4	25.0	24.1	0.9851
0	105	16.7	16.4	25.2	23.4	23.4	0.9869
3	105	17.1	17.2	23.1	23.4	24.2	0.9919
10	105	17.4	17.5	23.2	23.1	23.8	0.9926
17	105	16.9	16.9	23.1	24.0	24.1	0.9948
24	105	17.0	17.2	23.4	23.8	23.6	0.9945
31	105	16.8	17.1	23.5	23.9	23.8	0.9971
38	105	17.3	17.4	23.3	23.4	23.7	0.9951
45	105	16.9	17.0	23.6	23.6	23.9	1.0010
49	105	16.8	17.1	23.5	23.5	24.1	1.0018

Table A7. Summary of ATR Shim Positions for ATR Cycle 149A 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	51.2	1 1 1 1 1 1	51.2	1 1 1 0 1 1	0.0	1 1 1 0 1 1
NE	51.2	1 1 1 1 1 1	153.9	1 1 1 1 1 1	0.0	1 1 1 0 1 1	51.2	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	51.2	1 1 1 1 1 1	0.0	1 1 1 1 1 1	153.9	1 1 1 0 1 1	51.2	1 1 1 0 1 1
SE	0.0	1 1 1 1 1 1	51.2	1 1 1 1 1 1	51.2	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

Lobe	Total Core Power (MW)	Lobe Powers (MW) NW	NE	CR	SW	SE	$K_{effective}$
NW	105	26.8760	14.5820	24.3083	23.2000	16.0391	0.992523
NE	105	14.4534	27.7522	24.1453	16.2073	22.4418	0.994061
CR	105	15.5376	15.5809	31.6382	21.3825	20.8608	1.019802
SW	105	12.5618	8.8300	22.2392	42.4757	18.8933	1.020193
SE	105	8.9837	12.9705	22.3986	19.5927	41.0546	1.019413

Table A9. Summary of Fuel Element Powers for ATR Cycle 149A

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	105	2.7	2.6	2.1	1.5	1.1	1.2	1.5	2.3	2.9	2.9
0	105	2.8	2.6	2.3	1.6	1.3	1.4	1.7	2.4	3.0	3.0
3	105	2.7	2.7	2.3	1.8	1.6	1.6	1.8	2.4	3.0	2.8
10	105	2.8	2.8	2.3	1.8	1.6	1.6	1.9	2.5	3.0	2.8
17	105	2.7	2.7	2.3	1.7	1.5	1.6	1.8	2.4	2.9	2.8
24	105	2.8	2.8	2.3	1.8	1.5	1.6	1.8	2.4	3.0	2.9
31	105	2.9	2.8	2.3	1.7	1.5	1.5	1.8	2.4	3.0	2.9
38	105	2.9	2.8	2.4	1.8	1.6	1.6	1.8	2.5	3.0	2.9
45	105	2.8	2.7	2.3	1.8	1.5	1.6	1.8	2.4	2.9	2.9
49	105	2.7	2.7	2.3	1.8	1.6	1.6	1.9	2.4	2.8	2.8

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	105	3.3	3.5	3.3	2.6	2.2	2.3	2.7	3.6	3.9	3.7
0	105	3.3	3.5	3.2	2.5	2.1	2.2	2.6	3.5	3.8	3.6
3	105	2.9	3.1	3.2	2.8	2.6	2.8	2.9	3.4	3.4	3.1
10	105	2.9	3.1	3.1	2.8	2.5	2.7	2.9	3.4	3.3	3.1
17	105	2.9	3.2	3.2	2.7	2.5	2.7	2.9	3.4	3.5	3.1
24	105	2.9	3.2	3.1	2.7	2.5	2.6	2.8	3.4	3.4	3.0
31	105	2.9	3.3	3.2	2.7	2.4	2.6	2.8	3.4	3.5	3.1
38	105	3.0	3.3	3.1	2.6	2.4	2.5	2.7	3.4	3.6	3.1
45	105	3.1	3.4	3.2	2.6	2.4	2.5	2.7	3.4	3.6	3.3
49	105	3.1	3.4	3.2	2.7	2.5	2.6	2.8	3.4	3.6	3.3

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	105	3.7	3.9	3.7	3.0	2.3	2.3	2.8	3.3	3.6	3.3
0	105	3.6	3.8	3.5	2.7	2.1	2.1	2.6	3.2	3.5	3.3
3	105	3.1	3.3	3.3	2.9	2.5	2.5	2.7	3.0	3.1	2.9
10	105	3.1	3.3	3.3	2.8	2.5	2.5	2.7	3.0	3.1	2.9
17	105	3.1	3.3	3.4	3.0	2.6	2.6	2.8	3.1	3.1	2.9
24	105	3.0	3.3	3.4	3.0	2.6	2.6	2.8	3.1	3.1	2.9
31	105	3.0	3.4	3.4	3.0	2.6	2.6	2.8	3.1	3.2	2.8
38	105	3.0	3.3	3.3	2.9	2.5	2.5	2.7	3.0	3.1	2.8
45	105	3.1	3.5	3.3	2.9	2.4	2.4	2.7	3.0	3.3	2.9
49	105	3.2	3.5	3.3	2.9	2.4	2.4	2.7	3.0	3.3	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	105	3.0	3.0	2.2	1.5	1.1	1.1	1.4	2.1	2.7	2.8
0	105	3.0	3.1	2.4	1.7	1.4	1.4	1.7	2.3	2.8	2.8
3	105	2.8	3.0	2.3	1.8	1.6	1.5	1.7	2.3	2.8	2.7
10	105	2.9	3.1	2.4	1.8	1.6	1.6	1.8	2.3	2.9	2.8
17	105	2.9	3.0	2.3	1.8	1.5	1.5	1.7	2.3	2.9	2.8
24	105	3.0	3.1	2.3	1.7	1.5	1.5	1.7	2.3	2.9	2.9
31	105	2.9	3.0	2.3	1.7	1.5	1.5	1.7	2.2	2.9	2.9
38	105	2.9	3.0	2.3	1.8	1.6	1.6	1.8	2.3	2.9	2.8
45	105	2.8	2.9	2.2	1.8	1.7	1.6	1.8	2.2	2.8	2.7
49	105	2.8	2.8	2.2	1.8	1.6	1.6	1.7	2.2	2.7	2.7

Title: RESULTS OF REACTOR PHYSICS SAFETY ANALYSIS FOR ADVANCED TEST REACTOR (ATR) CYCLE 149A WITH NW-160 IN NW LOBE

ECAR No.: 1400 | ECAR Rev. No.: 0 | Project File No.: | Date: 02/28/2011

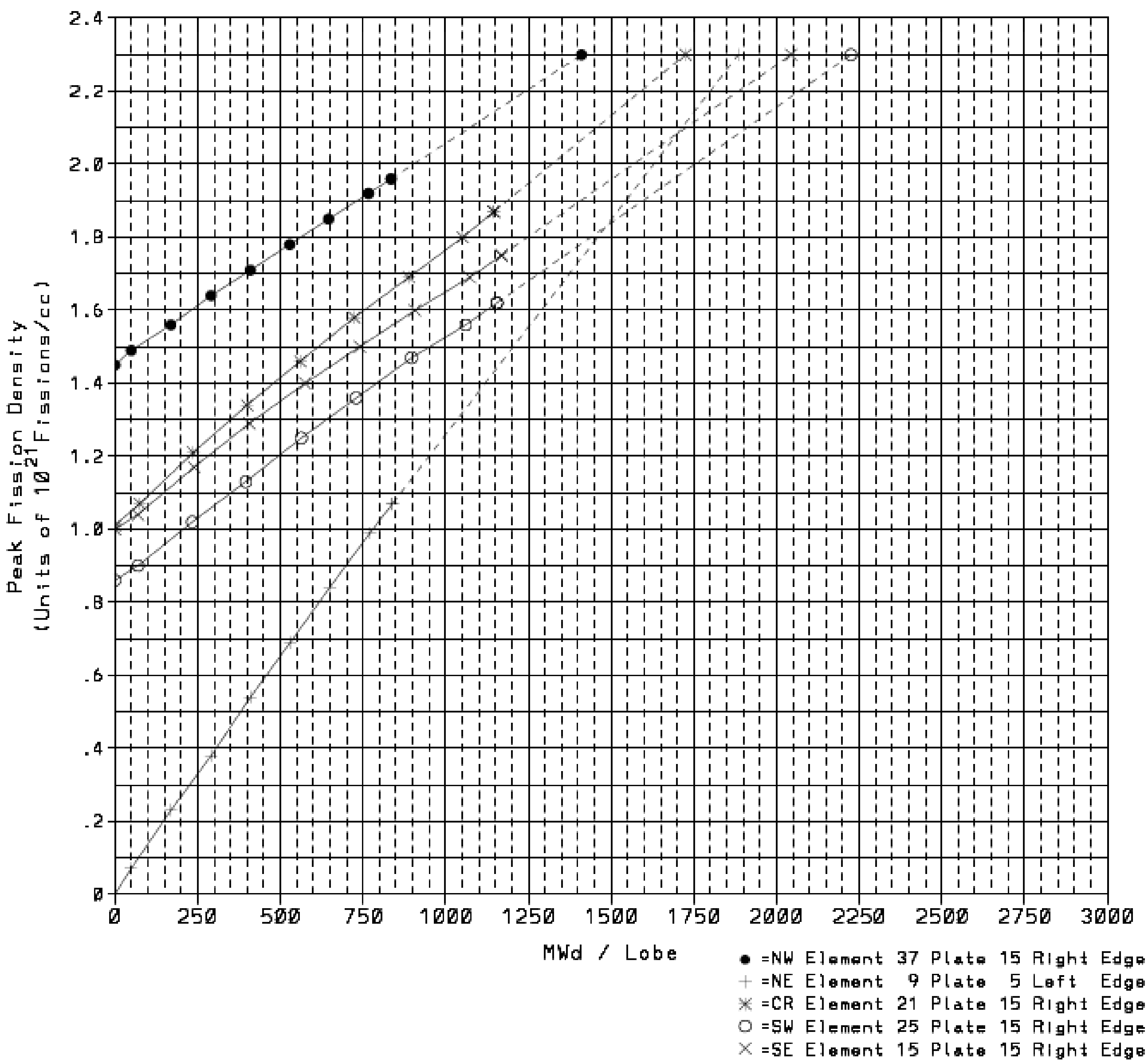

Figure A1. Fission Density for the Limiting Element in each Lobe For Cycle 149A-1

Title: RESULTS OF REACTOR PHYSICS SAFETY ANALYSIS FOR ADVANCED TEST REACTOR (ATR) CYCLE 149A WITH NW-160 IN NW LOBE

ECAR No.: 1400 ECAR Rev. No.: 0 Project File No.: Date: 02/28/2011

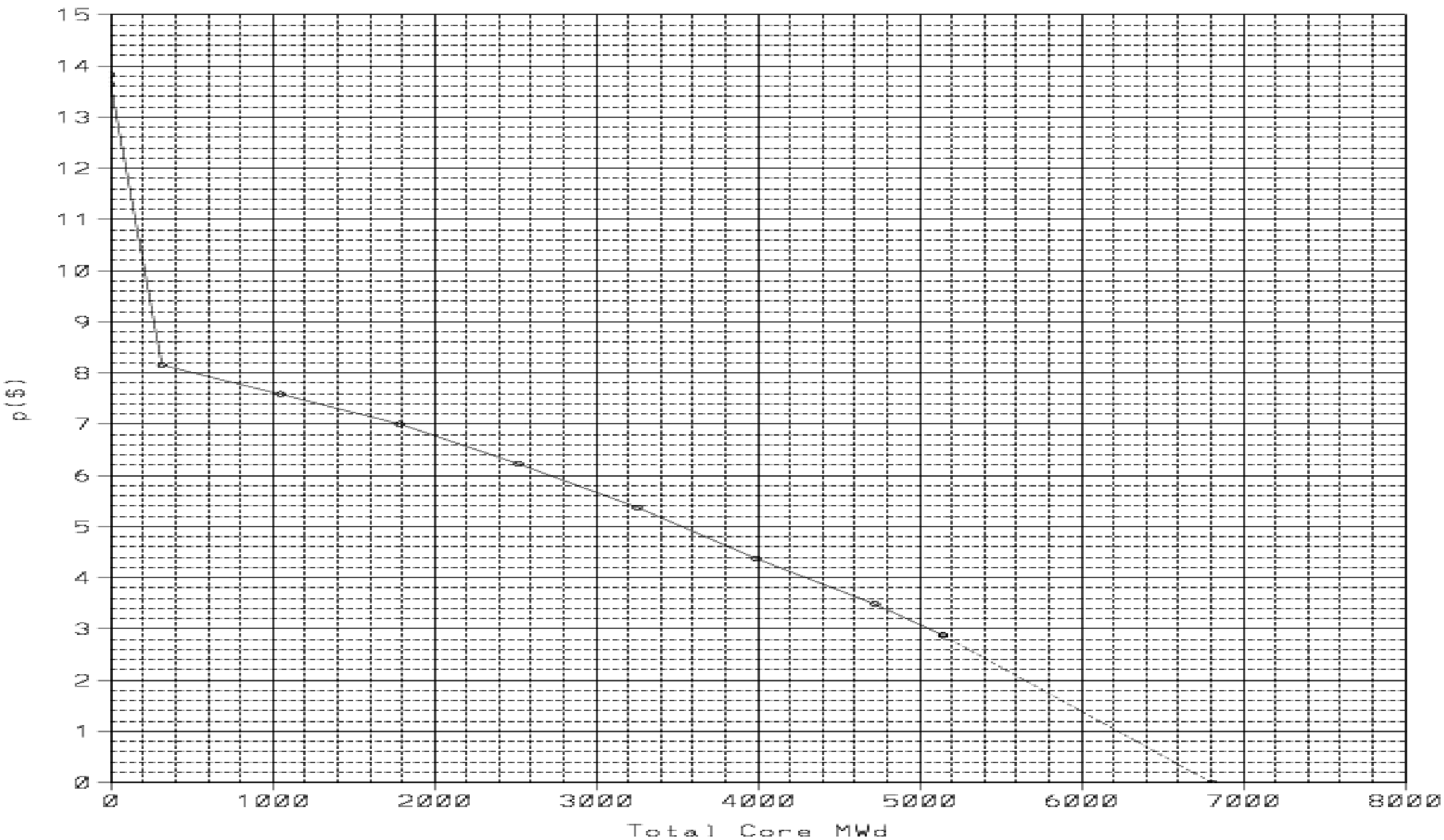

Figure A2. Estimated Total Core Excess Reactivity During ATR Cycle 149A-1