INL/MIS-22-65929-Revision-0

ECAR-1158 Results Of Reactor Physics Safety Analysis For Advanced Test Reactor (ATR) Cycle 148A

December 2007

Changing the World's Energy Future

Mitchell A Plummer

Idaho National Laboratory

INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance, LLC

INL/MIS-22-65929-Revision-0

ECAR-1158 Results Of Reactor Physics Safety Analysis For Advanced Test Reactor (ATR) Cycle 148A

Mitchell A Plummer

December 2007

Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

TEM-10200-1
12/11/2007
Rev. 01

ECAR No.: 1158 ECAR Rev. No.: 0 Project File No.: ____________

Title: RESULTS OF REACTOR PHYSICS SAFETY ANALYSIS FOR ADVANCED TEST REACTOR (ATR) CYCLE 148A

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

2. Quality Level: 1 *(Required Element)*

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 148A will run at a total core power of 104 MW for a nominal 56 days. Attached are the reactor physics data in support of the ATR Core Safety Assurance Program for Cycle 148A. The physics analysis contained herein was performed using a total core power of 104 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 148A when in 2-PCP operation.

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

		Typed Name/Organization	Signature/Date[2]
Performer/Author		A. W. LaPorta/W321/GB20	[signature] 8/10/10
Data Verifier	R	C. C. McKenzie/W321/GB20	[signature] for C.C. McKenzie per telecon 8/10/10
Technical Checker	R	P. A. Roth/W321/GB20	Pages checked: ALL [signature] for P.A. Roth per telecon 8/10/10
Independent Peer Reviewer[3]	R		
Performer's Manager	A	D. T. McDaniel/W410/GB25	[signature] 8/12/10
Requester	Ac		
Nuclear Safety[3]	Ac	N/A	

CUI See ECL 583478

1 Review and Approval are required. See LWP-10200 for definitions and responsibilities.
2 An Electronic Change Request (ECR) indicating final review and concurrence by the listed individuals can be used in lieu of signatures.
3 If Required, per LWP-10200.

6. Additional Distribution: (Name and Mail Stop) — Document Control: Document Control, MS 7116

J. D. Abrashoff, MS 7136; B. M. Blackburn, MS 7136 ; G. S. Chang, MS 3870; J. C. Chapman, MS 7136; B. M. Chase, MS 7136; B. J. Curnutt, MS 7104 ; D. E. Hale, MS 7136; J. A. Jacobi, MS 7114; A. W. LaPorta, MS 7136; D. T. McDaniel, MS 7136; Z. S. Miller, MS 7104 ; M. K. Morrison, MS 7101; C. C. McKenzie, MS 3201; S. R. Morrell, MS 7136; S. R. Novascone, MS 3720; P. A. Roth, MS 3201; C. J. Stanley, MS 7136; W. F. Steinke, MS 3407; E. T. Swain, MS 7136; T. C. Unruh, MS 7136; ATR File, MS 3201; CSAP File, MS 7136

Doc Control Laura Smith [signature] 8/18/10

ECAR No.: 1158 ECAR Rev. No.: 0 Project File No.: ______ Date: 8/18/10

Title: RESULTS OF REACTOR PHYSICS SAFETY ANALYSIS FOR ADVANCED TEST REACTOR (ATR) CYCLE 148A

Contents

Attachments

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

Scope and Brief Description

See above.

Design Inputs and Sources

a. Quality level source: QL Determination # RTC-000088
b. 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
c. 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.

Body

See attachment.

Recommendations/Conclusions

See attachment.

PE Stamp

N/A

References

a. See attachment.

Attachment

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

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 148A was run for 56 days (Ref. 5) using a nominal lobe power (MW) division of 18-18-24-21-23 (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 21-19.5-27-26-26 (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 148A fuel charge consists of the following fuel elements:

18 New 7F elements	15 recycle 7F elements
2 New NB elements	0 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. By the end of the previous reactor cycle, the exposure of the reflector adjacent to the SW and SE lobes is expected to have 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 148A. 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-39	5	100	10	201
NE	362	385	F-9	5	100	0	203
CR	362	385	F-20	5	100	0	216
SW	362	385	F-22	5	100	0	251
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-39	5	100	10	201
NE	362	385	F-9	5	100	0	203
SW	362	385	F-22	5	100	0	251
SE	362	385	F-19	5	100	0	232

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	167
NE	362	387	F-8	19	100	0	160
CR	362	387	F-30	19	100	3	138
SW	362	387	F-23	19	100	0	220
SE	362	387	F-18	19	100	0	206

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 148A 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 148A Most Limiting EPP
19	362	23	19	100	0	220
Inner	362	22	5	100	0	251
19	362	23	19	100	3	204
Inner	362	22	5	100	3	221
19	362	23	19	100	10	203
Inner	362	22	5	100	10	223
19	362	23	19	100	17	197
Inner	362	22	5	100	17	216
19	362	23	19	100	24	196
Inner	362	22	5	100	24	221
19	362	23	19	100	31	191
Inner	362	22	5	100	31	220
19	362	23	19	100	38	188
Inner	362	22	5	100	38	224
19	362	23	19	100	45	184
Inner	362	22	5	100	45	229
19	362	23	19	100	52	181
Inner	362	22	5	100	52	232
19	362	23	19	100	56	175
Inner	362	22	5	100	56	223

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 148A 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	100
SW/Plate 19	311	310	137	26	19	3	100
SE/Inner Plates	353	374	179	17	15	56	100
SE/Plate 19	311	310	167	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 $\times 10^{21}$ 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, 36
17	1,10, 35,36, 40
24	1,10,11,30,35,36, 40
31	1,10,11,15,20,21,26,27,30,31,35,36,40
38	1,10,11,15,16,20,21,24,26,27,30,31,34,35,36,40
45	1,10,11,15,16,20,21,24,25,26,27,30,31,34,35,36,37,40
52	1,5,10,11,15,16,20,21,24,25,26,27,30,31,34,35,36,37,40
56	1,5,10,11,15,16,20,21,24,25,26,27,30,31,34,35,36,37,40

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 148A Most Limiting Effective Point Power By Lobe				
	2 PCP	3 PCP	Pos.	Plate	Restricted to (%) of limit	Days	EPP
NW	446	465	F-37	15	100	45	159
NE	446	465	F-5	15	100	56	118
CR	446	465	F-20	5	100	31	246
SW	435	453	F-24	15	100	38	219
SE	435	453	F-15	15	100	31	171

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 148A Most Limiting Effective Point Power By Lobe				
	2 PCP	3 PCP	Pos.	Plate	Restricted to (%) of limit	Days	EPP
NW	411	428	F-37	19	100	45	126
NE	411	428	F-5	19	100	52,56	95
CR	411	428	F-40	19	100	17	160
SW	411	428	F-26	19	100	31	149
SE	411	428	F-15	19	100	31	132

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	26.62	All, inner plates	208	F-38	15	1.00	659/1.45 = 454	58.1*
			All, plate 19	202	F-38	19	1.00	659/1.45 = 454	59.8
NE	19.5	27.31	All, inner plates	207	F-9	5	1.00	659/1.45 = 454	59.8*
			All, plate 19	198	F-7	19	1.00	659/1.45 = 454	62.6
C	27.0	31.05	All, inner plates	228	F-21	5	1.00	659/1.45 = 454	61.8*
			All, plate 19	156	F-11	19	1.00	659/1.45 = 454	90.3
SW	26.0	38.53	All, inner plates	294	F-23	15	1.00	659/1.45 = 454	59.4
			All, plate 19	273	F-23	19	1.00	659/1.45 = 454	64.0
			< 2 sigma, inner plates	281	F-24	15	1.00	641/1.45 = 442	60.6
			< 2 sigma, plate 19	247	F-26	19	1.00	490/1.37 = 357	55.6*
SE	26.0	41.57	All, inner plates	315	F-17	15	1.00	659/1.45 = 454	59.9
			All, plate 19	299	F-17	19	1.00	659/1.45 = 454	63.1
			< 2 sigma, inner plates	315	F-17	15	1.00	641/1.45 = 442	58.3
			< 2 sigma, plate 19	299	F-17	19	1.00	490/1.37 = 357	49.6*

* 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 148A is 4.12 MW in core position F-22.

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 2.52 in position F-18 for the time step 0.

The preliminary startup power division normalized to a total core power of 250 MW is: 35.7-38.5-57.4-57.5-60.9(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 X 10^{21} fissions/cc)**	
Lobe	**MWd**	**Time in Cycle[b] (Days)**	**MWd**	**Time in Cycle[c] (Days)**
NW	988	54.8	1947	92.7
NE	1089	60.5	1953	100.1
C	---	---	1626	60.2
SW	1511	71.9	1970	75.7
SE	1659	72.1	2224	85.5

a. The reactivity estimates were obtained using the XSPRJ method.
b. The Time in Cycle is based on the nominal power division of 18-18-24-21-23 (NW-NE-CR-SW-SE).
c. The Time in Cycle is based on the maximum power division of 21-19.5-27-26-26 (NW-NE-CR-SW-SE).

The results above show sufficient reactivity to sustain the requested lobe power for the cycle length of 56 days 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 56 days. The reactivity and fission density data are shown in Figures A1 and A2.

All of the elements in the fuel loading for Cycle 148A are expected to have further recycle potential after the nominal operation of Cycle 148A except for the following:

Pos.	Serial No.
10	XA302T

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
goppl	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

1. R. T. McCracken letter to Distribution, RTMc-03-98, UFSAR/TSR Conversion Plan for the ATR Core Safety Assurance Program, Revision 1, March 5, 1998
2. S.T. Polkinghorne, Analysis of ATR 3-inch and 6-inch LOCA's for 110MW Two-Pump Operation, TRA-ATR-1374, October 1998
3. R. T. McCracken letter to J. D. Abrashoff, RTMc-18-98, Determination Of Corner Lobe Powers For Quadrant Differential Temperature Setting, June 3, 1998
4. Davis, C. B., Compliance With ATR SAR Commitment on fuel Design Temperatures, TEV-556, October 29, 2009
5. D. L. Rowsell letter to A. W. LaPorta, DLR-14-10, Rev.1, Advanced Test Reactor Cycle 148A Preliminary Experiment Requirements Letter, Revision 1, July 29, 2010
6. D. T. McDaniel letter to ATR Cycle Reference Document 15, DTM-5-10, Requested Lobe Powers for Advanced Test Reactor (ATR) Cycle 148A-1 Startup, August 4, 2010
7. A. C. Smith letter to R. T. McCracken, ACS-23-96, Updated References for the Advanced Test Reactor (ATR) Core Safety Assurance Calculations, July 19, 1996
8. A. C. Smith letter to R. T. McCracken, ACS-07-97, Average Axial Peaking Factors Incorporated in ROSUB and POWCOR For Use With The New TSR, February 24, 1997
9. S.T. Polkinghorne, Power Limits for ATR Fuel Plates with Less-Than-Nominal Thickness Coolant Channels, TRA-ATR-1601, July 2000
10. BEA SP, SP-10.6.2.2, ATR Fuel Element Receipt, Performance Assurance, And Release, Rev 8, December 11, 2007
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 148A[5,6]

Lobe	Power	Loop Experiments
NW	18 (+3 / -3)	2E/NW-100 R#1
N	-	1D/N-104 Med. 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	24 (+3 / -4)	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, and Aluminum Fillers in E5-E7
SW	21 (+5 / -1)	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 148A

Core Pos.	Serial No.	Content ^{235}U	^{10}B	Total MWD	Irradiation History Cycle	Pos.	Cycle	Pos.	Cycle	Pos.	Cycle	Pos.
1	XA814T	825	0.112	1408	145B-1	29						
2	XA633TNB	1075	0.000									
3	XA875T	1075	0.660									
4	XA876T	1075	0.660									
5	XA850T	868	0.139	1300	146A-1	24						
6	XA820T	889	0.164	1313	146A-1	15						
7	XA877T	1075	0.660									
8	XA878T	1075	0.660									
9	XA634TNB	1075	0.000									
10	XA302T	793	0.071	1658	133B-1	13						
11	XA827T	845	0.114	1408	145A-1	13						
12	XA862T	1075	0.660									
13	XA865T	1075	0.660									
14	XA869T	1075	0.660									
15	XA690T	868	0.138	1197	142B-1	38						
16	XA854T	879	0.152	1300	146A-1	27						
17	XA872T	1075	0.660									
18	XA873T	1075	0.660									
19	XA874T	1075	0.660									
20	YA503TM	839	0.118	1193	142A-1	24						
21	YA504TM	840	0.120	1200	135B-1	17						
22	XA886T	1075	0.660									
23	XA887T	1075	0.660									
24	YA426TM	858	0.153	793	132A-1	39						
25	YA482TM	858	0.139	1165	134B-1	16						
26	XA724T	852	0.139	1315	143A-1	29						
27	XA838T	870	0.141	1300	145A-1	24						
28	XA888T	1075	0.660									
29	XA893T	1075	0.660									
30	XA813T	836	0.104	1408	145B-1	28						
31	YA513TM	837	0.116	1323	142B-1	26						
32	XA879T	1075	0.660									
33	XA880T	1075	0.660									
34	XA818T	878	0.150	1313	146A-1	14						
35	XA638T	805	0.085	1630	140B-1	22	144A-1	4				
36	XA320T	822	0.096	1761	134A-1	19	135B-1	7	136B-1	15		
37	XA807T	876	0.148	1191	144B-1	13						
38	XA881T	1075	0.660									
39	XA882T	1075	0.660									
40	XA641T	816	0.099	1478	145B-1	12						

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

Core Pos.	Serial No.	Restriction	Restricted Plates (of those represented in the PDQ model)
1	XA814T		
2	XA633TNB		
3	XA875T		
4	XA876T		
5	XA850T		
6	XA820T		
7	XA877T		
8	XA878T		
9	XA634TNB		
10	XA302T		
11	XA827T		
12	XA862T		
13	XA865T		
14	XA869T		
15	XA690T		
16	XA854T		
17	XA872T		
18	XA873T		
19	XA874T		
20	YA503TM		
21	YA504TM		
22	XA886T		
23	XA887T		
24	YA426TM		
25	YA482TM		
26	XA724T		
27	XA838T		
28	XA888T		
29	XA893T		
30	XA813T		
31	YA513TM		
32	XA879T		
33	XA880T		
34	XA818T		
35	XA638T		
36	XA320T		
37	XA807T		
38	XA881T		
39	XA882T		
40	XA641T		

Table A4. Capsule Facility Loading Used in ATR Cycle 148A 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-04-10
E-2	AFC-2E	KEB-04-10
E-3	GFR-F1-2	KEB-04-10
E-4	UW-2	KEB-04-10
E-5	Aluminum Filler	KEB-04-10
E-6	Aluminum Filler	KEB-04-10
E-7	Aluminum Filler	KEB-04-10
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-1-6	GWW-05-10
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	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 through I-20	Beryllium Filler	
I-21 through I-24	Aluminum Filler	

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

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	61.0	1 2 3 4 5 6	61.0	1 2 3 4 5 6	61.0	1 2 3 5 6	61.0	1 2 3 5 6
0	79.3	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	85.4	1 2 3	79.3	1 2 3 5 6	85.4	1 2 3 5 6
10	85.4		85.4	1 2 3	79.3	1 2 3 5 6	85.4	1 2 3 5
17	89.8		85.4	1 2	85.4	1 2 3 5 6	85.4	1 2 3 5
24	95.2		85.4	1	85.4	1 2 3 5 6	85.4	1 2 3
31	95.2		85.4		85.4	1 2 3 5	85.4	1 2 3
38	104.2		89.8		85.4	1 2 3	85.4	1
45	104.2		95.2		85.4	1	85.4	
52	111.7		104.2		85.4		95.2	
56	116.4		111.7		95.2		100.1	

Table A6. Summary of ATR Core Power and Calculated $K_{effective}$ for ATR Cycle 148A

Time at Power (Days)	Total Core Power (MW)	Lobe Powers (MW) NW	NE	CR	SW	SE	$K_{effective}$
0	104	14.9	16.0	23.9	23.9	25.3	0.9922
0	104	17.6	17.6	23.8	21.3	23.7	0.9916
3	104	17.1	17.8	23.0	22.1	24.1	0.9929
10	104	17.1	17.4	23.1	21.8	24.6	0.9938
17	104	17.3	17.4	22.8	22.3	24.1	0.9944
24	104	17.4	17.6	22.9	21.5	24.6	0.9960
31	104	17.3	17.6	23.0	21.8	24.2	0.9956
38	104	17.4	17.5	23.1	21.8	24.2	0.9988
45	104	17.0	17.4	23.5	22.2	23.9	1.0001
52	104	16.9	17.8	23.1	21.5	24.6	0.9997
56	104	16.8	17.8	22.6	22.2	24.6	0.9999

Table A7. Summary of ATR Shim Positions for ATR Cycle 148A 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	69.7	1 1 1 1 1 1	51.2	1 1 1 0 1 1	0.0	1 1 1 0 1 1
NE	79.3	1 1 1 1 1 1	153.9	1 1 1 1 1 1	0.0	1 1 1 0 1 1	56.6	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	79.3	1 1 1 1 1 1	0.0	1 1 1 1 1 1	153.9	1 1 1 0 1 1	56.6	1 1 1 0 1 1
SE	0.0	1 1 1 1 1 1	69.7	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

	Total Core Power	Lobe Powers (MW)					
Lobe	(MW)	NW	NE	CR	SW	SE	$K_{effective}$
NW	104	26.62	17.51	23.33	20.71	15.82	0.993374
NE	104	16.93	27.31	22.91	14.62	22.23	0.998471
CR	104	14.88	16.49	31.05	20.33	21.24	1.017375
SW	104	14.75	9.36	21.63	38.53	19.74	1.019399
SE	104	8.42	14.82	21.45	17.75	41.57	1.021580

Table A9. Summary of Fuel Element Powers for ATR Cycle 148A

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	2.7	2.2	1.6	1.3	1.3	1.7	2.4	2.9	2.8
0	104	2.7	2.9	2.4	1.9	1.5	1.5	1.9	2.5	3.0	2.8
3	104	2.7	2.9	2.4	1.9	1.6	1.6	1.9	2.4	3.0	2.8
10	104	2.7	2.9	2.3	1.8	1.6	1.6	1.9	2.4	2.9	2.7
17	104	2.7	2.9	2.4	1.8	1.6	1.6	1.9	2.4	2.9	2.8
24	104	2.8	2.9	2.4	1.9	1.6	1.6	1.9	2.4	3.0	2.9
31	104	2.9	2.9	2.4	1.9	1.6	1.6	1.9	2.4	3.0	2.9
38	104	2.8	2.8	2.4	1.9	1.6	1.6	1.9	2.4	2.9	2.9
45	104	2.8	2.8	2.3	1.9	1.6	1.6	1.9	2.4	2.9	2.8
52	104	2.7	2.7	2.4	2.0	1.7	1.7	2.0	2.5	2.9	2.8
56	104	2.6	2.7	2.4	2.0	1.7	1.7	2.0	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	3.2	3.5	3.3	3.0	2.5	2.5	3.1	3.7	3.8	3.4
0	104	3.1	3.4	3.2	2.7	2.2	2.2	2.8	3.5	3.6	3.3
3	104	2.9	3.1	3.1	2.9	2.6	2.7	3.0	3.4	3.3	3.0
10	104	2.9	3.2	3.2	2.9	2.7	2.7	3.0	3.4	3.5	3.0
17	104	2.9	3.2	3.1	2.9	2.6	2.6	3.0	3.4	3.4	3.0
24	104	2.9	3.3	3.2	2.9	2.6	2.6	3.0	3.4	3.5	3.0
31	104	2.9	3.3	3.2	2.9	2.5	2.6	3.0	3.4	3.5	3.0
38	104	3.1	3.4	3.1	2.8	2.5	2.5	2.9	3.4	3.6	3.1
45	104	3.1	3.4	3.1	2.8	2.4	2.4	2.9	3.4	3.6	3.2
52	104	3.1	3.4	3.2	2.9	2.5	2.6	3.0	3.4	3.6	3.2
56	104	3.0	3.3	3.2	2.9	2.6	2.6	3.1	3.4	3.5	3.1

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	3.4	3.7	3.6	2.7	2.3	2.3	2.6	3.2	3.4	3.1
0	104	3.3	3.5	3.2	2.3	1.9	1.9	2.3	3.0	3.2	3.0
3	104	3.0	3.2	3.2	2.6	2.3	2.3	2.5	3.0	3.0	2.8
10	104	3.0	3.2	3.2	2.5	2.3	2.3	2.5	2.9	3.0	2.8
17	104	2.9	3.2	3.3	2.6	2.4	2.4	2.5	3.0	3.0	2.8
24	104	2.9	3.1	3.2	2.5	2.3	2.3	2.4	2.9	2.9	2.7
31	104	2.9	3.2	3.2	2.5	2.3	2.3	2.4	2.9	3.0	2.7
38	104	2.9	3.3	3.2	2.4	2.2	2.2	2.4	2.9	3.1	2.7
45	104	3.1	3.5	3.2	2.4	2.2	2.2	2.4	3.0	3.2	2.9
52	104	3.2	3.4	3.2	2.4	2.1	2.1	2.3	2.9	3.2	2.9
56	104	3.1	3.4	3.3	2.5	2.3	2.3	2.4	2.9	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	2.7	2.6	2.2	1.5	1.2	1.2	1.5	2.2	2.5	2.6
0	104	2.8	2.7	2.5	1.9	1.6	1.6	1.9	2.5	2.7	2.7
3	104	2.8	2.8	2.4	1.8	1.5	1.5	1.8	2.4	2.8	2.8
10	104	2.9	2.8	2.4	1.8	1.5	1.5	1.8	2.4	2.8	2.9
17	104	2.9	2.8	2.4	1.8	1.6	1.6	1.8	2.5	2.8	2.9
24	104	2.8	2.8	2.4	1.8	1.6	1.6	1.9	2.5	2.8	2.8
31	104	2.8	2.8	2.4	1.8	1.6	1.6	1.8	2.5	2.8	2.8
38	104	2.8	2.8	2.4	1.8	1.6	1.7	1.9	2.5	2.8	2.8
45	104	2.8	2.7	2.4	1.8	1.6	1.6	1.8	2.4	2.7	2.7
52	104	2.7	2.7	2.4	1.8	1.6	1.6	1.8	2.4	2.7	2.6
56	104	2.6	2.6	2.3	1.8	1.6	1.6	1.8	2.4	2.6	2.6

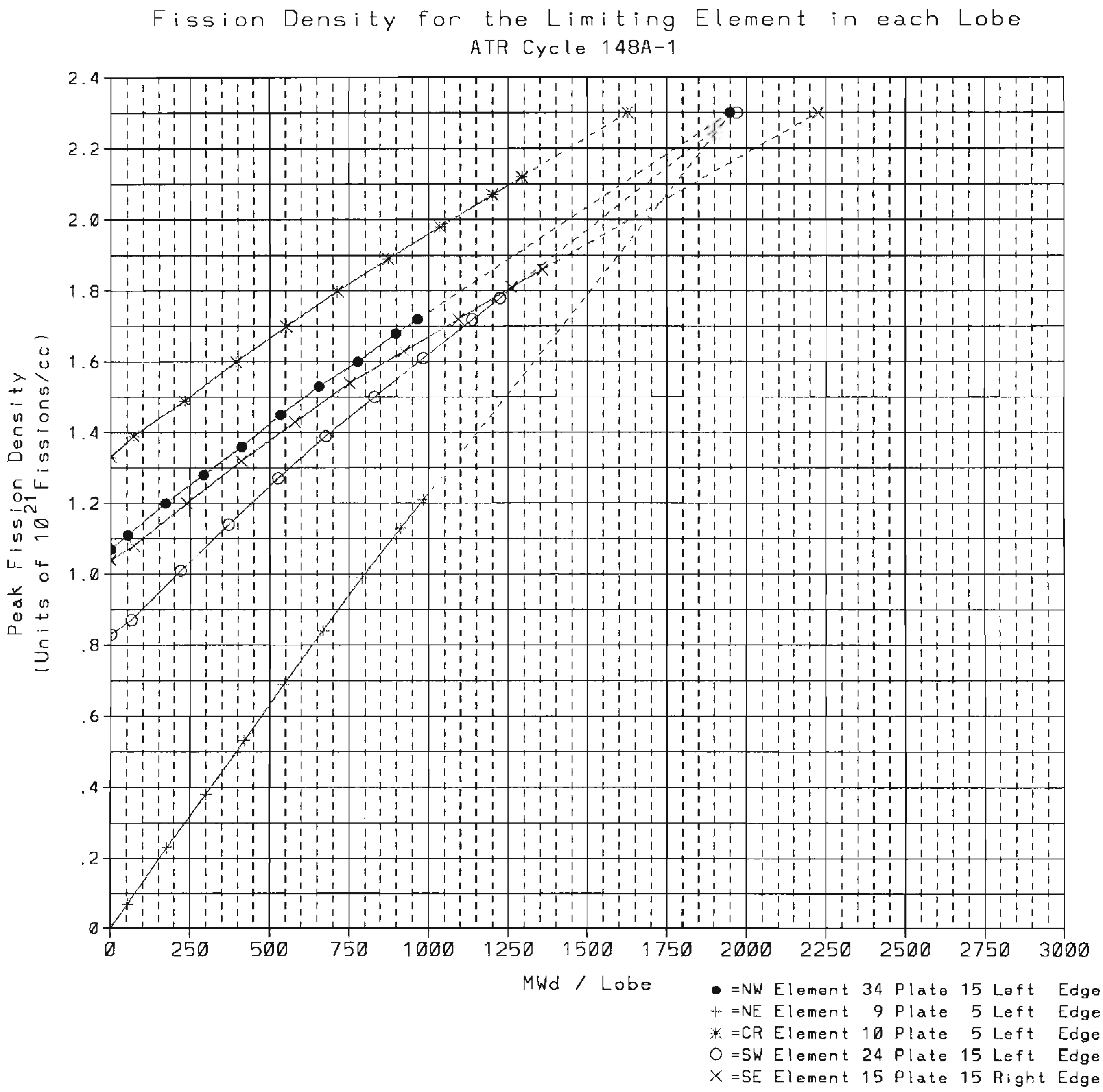

Figure A1. Fission Density for the Limiting Element in each Lobe For Cycle 148A-1

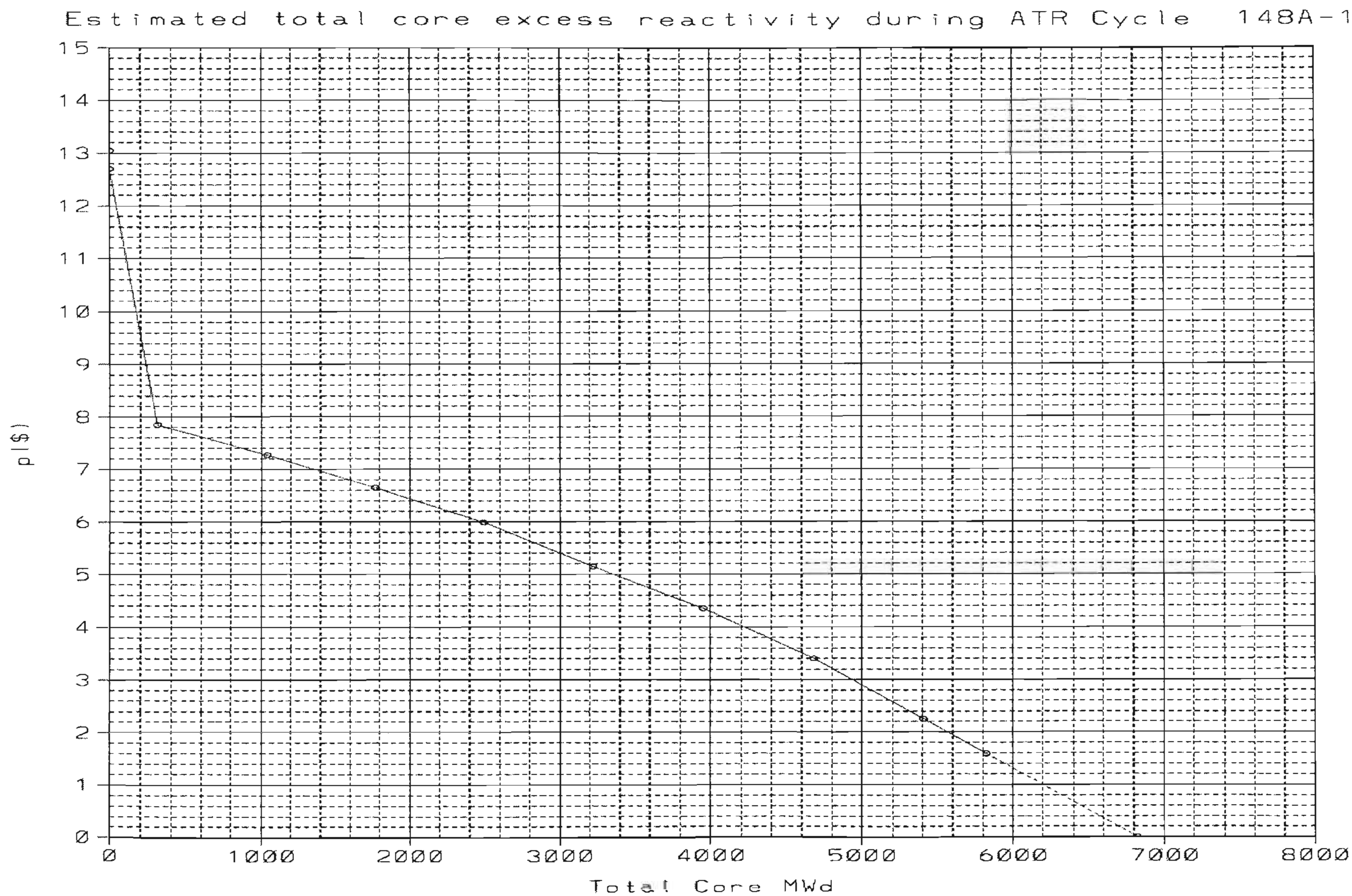

Figure A2. Estimated Total Core Excess Reactivity During ATR Cycle 148A-1