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ECAR No.: 1032 ECAR Rev. No.: 0 Project File No.: ____________

Title: RESULTS OF REACTOR PHYSICS SAFETY ANALYSIS FOR ADVANCED TEST REACTOR (ATR) CYCLE 147A

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 147A will run at a total core power of 114 MW for a nominal 49 days. Attached are the reactor physics data in support of the ATR Core Safety Assurance Program for Cycle 147A. The physics analysis contained herein was performed using a total core power of 110 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 147A when in 2-PCP operation.

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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.
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Title: RESULTS OF REACTOR PHYSICS SAFETY ANALYSIS FOR ADVANCED TEST REACTOR (ATR) CYCLE 147A

Contents

Attachments

Attachment 1 – Results of Reactor Physics Safety Analysis for Advanced Test Reactor (ATR) Cycle 147A.

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.

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Attachment

Results of Reactor Physics Safety Analysis for Advanced Test Reactor (ATR) Cycle 147A

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 147A was run for 49 days (Ref. 5) using a nominal lobe power (MW) division of 23-18-23-23-23 (NW-NE-CR-SW-SE) for a total reactor power of 110 MW. Effective plate power (EPP) values have been computed using maximum lobe powers (MW) of 24-19.5-32-26-26 (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). The nominal SW lobe power in Reference 6 is 21 MW rather than 23 MW as shown in Table A1. This is due to a change made after the physics analysis was completed. Performing the physics calculation with the higher SW nominal power makes only a small difference and is conservative.

3. Data

The Cycle 147A fuel charge consists of the following fuel elements:

18 New 7F elements	16 recycle 7F elements
0 New NB elements	0 recycle NB elements
0 New YA elements	0 recycle YA elements
0 New YA...M elements	6 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 147A. 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	220
NE	362	385	F-9	5	100	0	226
CR	362	385	F-21	5	100	3	262
SW	362	385	F-22	5	100	0	273
SE	362	385	F-19	5	100	0	260

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-31	5	100	3	234
NE	362	385	F-9	5	100	0	226
SW	362	385	F-22	5	100	0	273
SE	362	385	F-19	5	100	0	260

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	184
NE	362	387	F-3	19	100	0	171
CR	362	387	F-20	19	100	3	144
SW	362	387	F-23	19	100	0	231
SE	362	387	F-18	19	100	0	220

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 147A 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 147A Most Limiting EPP
19	362	23	19	100	0	231
Inner	362	22	5	100	0	273
19	362	23	19	100	3	209
Inner	362	21	5	100	3	262
19	362	23	19	100	10	205
Inner	362	21	5	100	10	261
19	362	23	19	100	17	199
Inner	362	21	5	100	17	257
19	362	23	19	100	24	195
Inner	362	21	5	100	24	253
19	362	23	19	100	31	190
Inner	362	21	5	100	31	248
19	362	23	19	100	38	184
Inner	362	21	5	100	38	238
19	362	23	19	100	45	180
Inner	362	21	5	100	45	233
19	362	23	19	100	49	179
Inner	362	22	5	100	49	232

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

Exposure is expected to exceed the value for the limiting A-ligament stress level in the SW and SE lobe during this cycle. 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 147A 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	164	24	15	31	100
SW/Plate 19	311	310	133	24	19	3	100
SE/Inner Plates	353	374	163	17	15	3,10,17	100
SE/Plate 19	311	310	134	16	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	10
10	1,10, 31,40
17	1,10,16, 20,25,30,31, 40
24	1,10,11,15,16,17,20,25,30,31, 40
31	1,10,11,14,15,16,17,20,21,24,25,27,30,31, 40
38	1,4,5,10,11,14,15,16,17,20,21,24,25,26,27,30,31, 40
45	1,4,5,6,10,11,14,15,16,17,20,21,24,25,26,27,30,31,36,40
49	1,4,5,6,8,10,11,14,15,16,17,20,21,24,25,26,27,30,31,36,40

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. Table 7 shows the calculated effective point power for the most limiting element in each lobe. Lobes with "NA" entries do not have any elements that exceed 1.5 x 10^{21} fission density during the cycle.

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

Lobe	Effective Point Power Limit		Cycle 147A Most Limiting Effective Point Power By Lobe				
	2 PCP	3 PCP	Pos.	Plate	Restricted to (%) of limit	Days	EPP
NW	428	442	F-36	15	100	45	149
NE	428	442	F-8	15	100	49	181
CR	428	442	F-20	5	100	17	306
SW	417	431	F-24	15	100	31	199
SE	417	431	F-17	15	100	24	195

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 8 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. 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 8. 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	24.0	33.69	All, inner plates	263	F-35	15	1.00	659/1.45 = 454	58.1*
			All, plate 19	257	F-35	19	1.00	659/1.45 = 454	59.5
NE	19.5	25.65	All, inner plates	204	F-9	5	1.00	659/1.45 = 454	57.0*
			All, plate 19	196	F-3	19	1.00	659/1.45 = 454	59.4
C	32.0	33.31	All, inner plates	250	F-21	5	1.00	659/1.45 = 454	60.4*
			All, plate 19	151	F-11	19	1.00	659/1.45 = 454	100.1
SW	26.0	40.77	All, inner plates	307	F-23	15	1.00	659/1.45 = 454	60.2
			All, plate 19	285	F-23	19	1.00	659/1.45 = 454	64.9
			< 2 sigma, inner plates	285	F-26	15	1.00	641/1.45 = 442	63.2
			< 2 sigma, plate 19	258	F-25	19	1.00	490/1.37 = 357	56.4*
SE	26.0	43.48	All, inner plates	326	F-18	15	1.00	659/1.45 = 454	60.5
			All, plate 19	301	F-18	19	1.00	659/1.45 = 454	65.5
			< 2 sigma, inner plates	291	F-17	17	1.00	641/1.45 = 442	66.0
			< 2 sigma, plate 19	272	F-16	19	1.00	490/1.37 = 357	57.0*

* indicates minimum value for the lobe

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 147A is 4.42 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 2.66 in position F-23 for the time step 0.

The preliminary startup power division normalized to a total core power of 250 MW is: 41.0-34.5-60.7-57.0-56.7 (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 9.

Table 9. 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	1285	55.8	2194	91.4
NE	957	53.1	1745	89.4
C	---	---	1583	49.4
SW	1777	77.2	1854	71.3
SE	1611	70.0	1898	73.0

a. The reactivity estimates were obtained using the XSPRJ method.
b. The Time in Cycle is based on the nominal power division of 23-18-29-23-23 (NW-NE-CR-SW-SE).
c. The Time in Cycle is based on the maximum power division of 24-19.5-32-26-26 (NW-NE-CR-SW-SE).

The results above show sufficient reactivity to sustain the requested lobe power for the cycle length of 49 days. 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 147A are expected to have further recycle potential after the nominal operation of Cycle 147A.

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 10. The V&V is documented in References 12 and 13.

Table 10. 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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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 147A[5,6]

Lobe	Power	Loop Experiments
NW	23 (+1 / -5)	2E/NW-159 R#0
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	29 (+3 / -7)	AFIP-6A/B
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	23 (+3 / -3)	2D/SW-184 STD R#3
S	-	AGC-1
SE	23 (+3 / -3)	2B/SE-218 STD BU R#0

Table A2. Summary of Fuel Load for Cycle 147A

Core Pos.	Serial No.	Content ^{235}U	Content ^{10}B	Total MWD	Irradiation History Cycle	Pos.	Cycle	Pos.	Cycle	Pos.	Cycle	Pos.
1	XA345T	791	0.071	2008	134B-1	7	136A-1	26				
2	XA902T	1075	0.660									
3	XA903T	1075	0.660									
4	XA679T	874	0.150	1466	141A-1	3	143A-1	6				
5	XA849T	838	0.103	1300	146A-1	23						
6	XA739T	840	0.109	1435	143B-1	13						
7	XA853T	891	0.168	1300	146A-1	26						
8	XA845T	913	0.201	907	146A-1	3						
9	XA905T	1075	0.660									
10	YA540TM	750	0.054	2000	144A-1	16	146A-1	37				
11	XA837T	836	0.102	1300	145A-1	23						
12	XA910T	1075	0.660									
13	XA912T	1075	0.660									
14	XA655T	871	0.137	1175	139B-1	28						
15	XA841T	839	0.104	1313	146A-1	18						
16	XA730T	841	0.125	1223	143A-1	19						
17	XA833T	868	0.138	1313	146A-1	17						
18	XA913T	1075	0.660									
19	XA914T	1075	0.660									
20	XA793T	821	0.089	1435	143B-1	18						
21	YA512TM	836	0.115	1323	142B-1	25						
22	XA906T	1075	0.660									
23	XA907T	1075	0.660									
24	XA725T	865	0.149	1223	143A-1	12						
25	XA587T	849	0.133	1048	138A-1	9						
26	YA514TM	847	0.124	1014	135C-1	18						
27	XA710T	866	0.148	1104	142A-1	19						
28	XA908T	1075	0.660									
29	XA909T	1075	0.660									
30	YA447TM	814	0.095	1336	138A-1	24						
31	YA545TM	772	0.075	1888	145A-1	4	146A-1	7				
32	XA891T	1075	0.660									
33	XA895T	1075	0.660									
34	XA897T	1075	0.660									
35	XA898T	1075	0.660									
36	XA706T	875	0.160	1104	142A-1	12						
37	XA899T	1075	0.660									
38	XA900T	1075	0.660									
39	XA901T	1075	0.660									
40	YA475TM	758	0.058	1807	134B-1	14	140B-1	37				

Table A3. Plate Restrictions for Fuel Loaded in Cycle 147A[9,10]

Core Pos.	Serial No.	Restriction	Restricted Plates (of those represented in the PDQ model)
1	XA345T		
2	XA902T		
3	XA903T		
4	XA679T		
5	XA849T		
6	XA739T		
7	XA853T		
8	XA845T		
9	XA905T		
10	YA540TM		
11	XA837T		
12	XA910T		
13	XA912T		
14	XA655T		
15	XA841T		
16	XA730T		
17	XA833T		
18	XA913T		
19	XA914T		
20	XA793T		
21	YA512TM		
22	XA906T		
23	XA907T		
24	XA725T		
25	XA587T		
26	YA514TM		
27	XA710T		
28	XA908T		
29	XA909T		
30	YA447TM		
31	YA545TM		
32	XA891T		
33	XA895T		
34	XA897T		
35	XA898T		
36	XA706T		
37	XA899T		
38	XA900T		
39	XA901T		
40	YA475TM		

Table A4. Capsule Facility Loading Used in ATR Cycle 147A Analysis[5]

Facility	Description	Reference
CFT	AFIP-6A/B	RBN-04-09
E-1	AFC-2D	KEB-02-10
E-2	AFC-2E	KEB-02-10
E-3	GFR-F1-2	KEB-02-10
E-4	UW-2	KEB-02-10
E-5	Aluminum Filler	KEB-02-10
E-6	Aluminum Filler	KEB-02-10
E-7	Aluminum Filler	KEB-02-10
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-1-5	GWW-02-10
A-12	Outboard A Flux Monitor Assembly	GEM-02-09
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
B-8	YSFR	
B-9	Aluminum Filler	
B-10	Aluminum Filler	
B-11	RERTR-12-3	RBN-08-10
B-12	AGR-2	SBG-01-10

Table A4. Continued

Facility	Description	Reference
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 147A

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	69.7	1 2 3 4 5 6	56.6	1 2 3 4 5 6	34.4	1 2 3 5 6	46.5	1 2 3 5 6
3	85.4		85.4	1 2 3 4 5	69.7	1 2 3 5 6	79.3	1 2 3 5 6
10	85.4		85.4	1 2 3 4 5	69.7	1 2 3 5 6	79.3	1 2 3 5 6
17	95.2		85.4	1 2 3 4	75.2	1 2 3 5 6	85.4	1 2 3 5 6
24	100.1		85.4	1 2 3	79.3	1 2 3 5 6	85.4	1 2 3 5
31	104.2		85.4	1 2	85.4	1 2 3 5 6	85.4	1 2 3
38	111.7		85.4		85.4	1 2 3	85.4	1 2
45	111.7		89.8		85.4	1 2	85.4	1
49	116.4		95.2		85.4	1	89.8	

Table A6. Summary of ATR Core Power and Calculated $K_{effective}$ for ATR Cycle 147A

Time at Power (Days)	Total Core Power (MW)	Lobe Powers (MW) NW	NE	CR	SW	SE	$K_{effective}$
0	110	18.0	15.2	26.7	25.1	25.0	0.9911
0	110	21.6	16.1	26.7	22.1	23.6	0.9902
3	110	21.6	16.5	25.0	22.8	24.1	0.9959
10	110	21.6	16.6	24.7	22.9	24.1	0.9920
17	110	22.4	16.5	24.0	22.9	24.0	0.9943
24	110	22.6	16.7	23.7	22.9	24.1	0.9956
31	110	22.5	16.7	23.6	23.0	24.2	0.9970
38	110	22.4	16.7	24.2	23.4	23.4	1.0038
45	110	22.1	16.9	24.3	23.4	23.3	1.0018
49	110	21.7	17.0	24.5	23.1	23.7	1.0049

Table A7. Summary of ATR Shim Positions for ATR Cycle 147A 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	56.6	1 1 1 1 1 1	34.4	1 1 1 0 1 1	0.0	1 1 1 0 1 1
NE	69.7	1 1 1 1 1 1	153.9	1 1 1 1 1 1	0.0	1 1 1 0 1 1	46.5	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	69.7	1 1 1 1 1 1	0.0	1 1 1 1 1 1	153.9	1 1 1 0 1 1	46.5	1 1 1 0 1 1
SE	0.0	1 1 1 1 1 1	56.6	1 1 1 1 1 1	34.4	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	110	33.69	15.16	25.00	20.02	16.13	1.000781
NE	110	20.23	25.65	25.29	17.03	21.79	0.999723
CR	110	17.44	15.52	33.31	21.89	21.83	1.030608
SW	110	17.13	9.41	23.53	40.77	19.16	1.024142
SE	110	10.65	13.68	23.84	18.34	43.48	1.021550

Table A9. Summary of Fuel Element Powers for ATR Cycle 147A

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	110	2.9	2.7	2.2	1.4	1.1	1.1	1.5	2.2	2.9	3.0
0	110	3.0	2.8	2.4	1.6	1.2	1.2	1.6	2.3	2.9	3.0
3	110	2.8	2.7	2.4	1.7	1.5	1.5	1.7	2.3	2.7	2.7
10	110	2.8	2.7	2.4	1.7	1.5	1.5	1.8	2.3	2.7	2.7
17	110	2.8	2.7	2.4	1.7	1.5	1.5	1.7	2.2	2.8	2.6
24	110	2.8	2.8	2.4	1.7	1.5	1.5	1.7	2.2	2.8	2.7
31	110	2.8	2.8	2.4	1.7	1.5	1.5	1.7	2.2	2.9	2.7
38	110	3.0	2.9	2.4	1.7	1.4	1.4	1.7	2.2	3.0	2.9
45	110	3.0	2.9	2.4	1.7	1.5	1.5	1.7	2.2	3.0	2.9
49	110	2.9	2.9	2.4	1.7	1.5	1.5	1.7	2.3	2.9	2.9

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	110	3.5	3.7	3.4	2.6	2.2	2.3	2.8	3.8	4.1	3.8
0	110	3.5	3.6	3.3	2.5	2.0	2.1	2.6	3.6	3.9	3.7
3	110	3.1	3.2	3.2	2.7	2.5	2.6	2.8	3.5	3.5	3.3
10	110	3.1	3.2	3.2	2.7	2.5	2.6	2.8	3.5	3.5	3.3
17	110	3.0	3.2	3.2	2.7	2.6	2.6	2.8	3.5	3.5	3.2
24	110	3.0	3.3	3.2	2.7	2.5	2.6	2.8	3.5	3.6	3.1
31	110	3.0	3.4	3.2	2.7	2.5	2.5	2.8	3.5	3.7	3.1
38	110	3.1	3.4	3.1	2.5	2.3	2.3	2.6	3.4	3.6	3.2
45	110	3.1	3.4	3.1	2.5	2.3	2.3	2.6	3.4	3.7	3.3
49	110	3.2	3.5	3.2	2.5	2.3	2.4	2.6	3.4	3.7	3.4

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	110	3.9	4.1	3.8	2.8	2.3	2.2	2.7	3.5	3.8	3.5
0	110	3.7	3.8	3.4	2.3	1.8	1.8	2.2	3.2	3.6	3.4
3	110	3.3	3.5	3.3	2.6	2.3	2.2	2.5	3.1	3.3	3.2
10	110	3.3	3.5	3.4	2.6	2.3	2.2	2.5	3.1	3.3	3.1
17	110	3.2	3.4	3.4	2.6	2.3	2.3	2.5	3.1	3.2	3.0
24	110	3.1	3.4	3.3	2.6	2.4	2.3	2.5	3.1	3.2	3.0
31	110	3.1	3.3	3.4	2.7	2.4	2.4	2.6	3.1	3.2	2.9
38	110	3.1	3.6	3.4	2.6	2.4	2.3	2.5	3.2	3.4	2.9
45	110	3.2	3.6	3.4	2.6	2.3	2.3	2.5	3.2	3.5	3.0
49	110	3.3	3.7	3.4	2.5	2.3	2.2	2.4	3.1	3.5	3.1

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	110	3.2	3.1	2.7	1.9	1.5	1.4	1.9	2.5	3.0	2.9
0	110	3.2	3.3	3.1	2.5	2.1	2.0	2.4	3.0	3.2	3.1
3	110	3.3	3.4	3.0	2.4	2.1	2.0	2.4	2.9	3.4	3.2
10	110	3.3	3.4	3.0	2.4	2.2	2.0	2.4	2.9	3.4	3.1
17	110	3.2	3.4	3.0	2.5	2.4	2.2	2.5	3.0	3.4	3.1
24	110	3.1	3.4	3.0	2.6	2.4	2.3	2.6	3.0	3.3	3.0
31	110	3.0	3.3	3.0	2.6	2.4	2.3	2.6	3.0	3.3	2.9
38	110	3.0	3.3	3.0	2.6	2.4	2.3	2.6	3.0	3.3	2.9
45	110	3.0	3.2	2.9	2.6	2.4	2.2	2.6	2.9	3.2	2.9
49	110	2.9	3.2	2.9	2.5	2.4	2.2	2.5	2.9	3.2	2.8

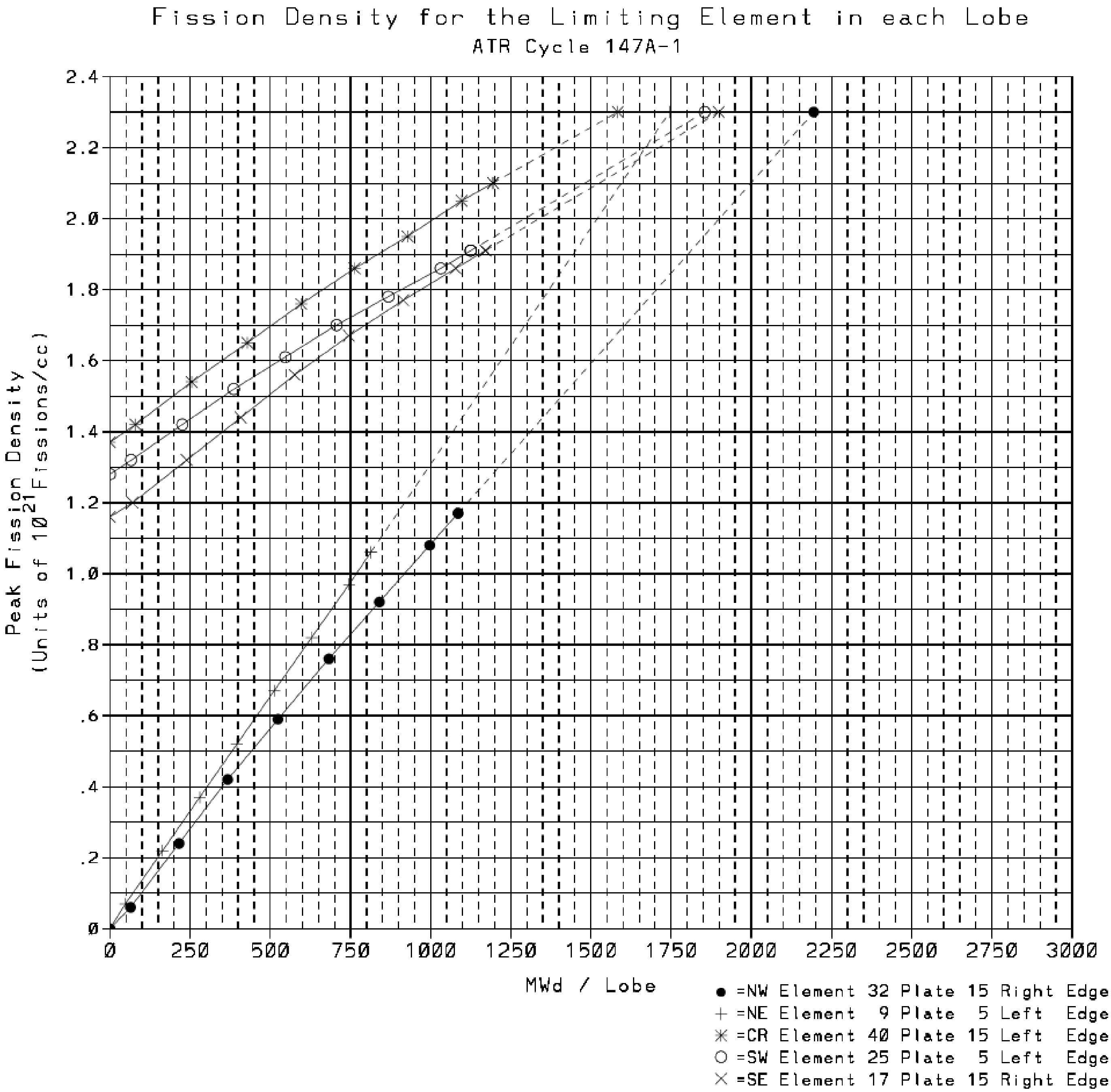

Figure A1. Fission Density for the Limiting Element in each Lobe For Cycle 147A-1

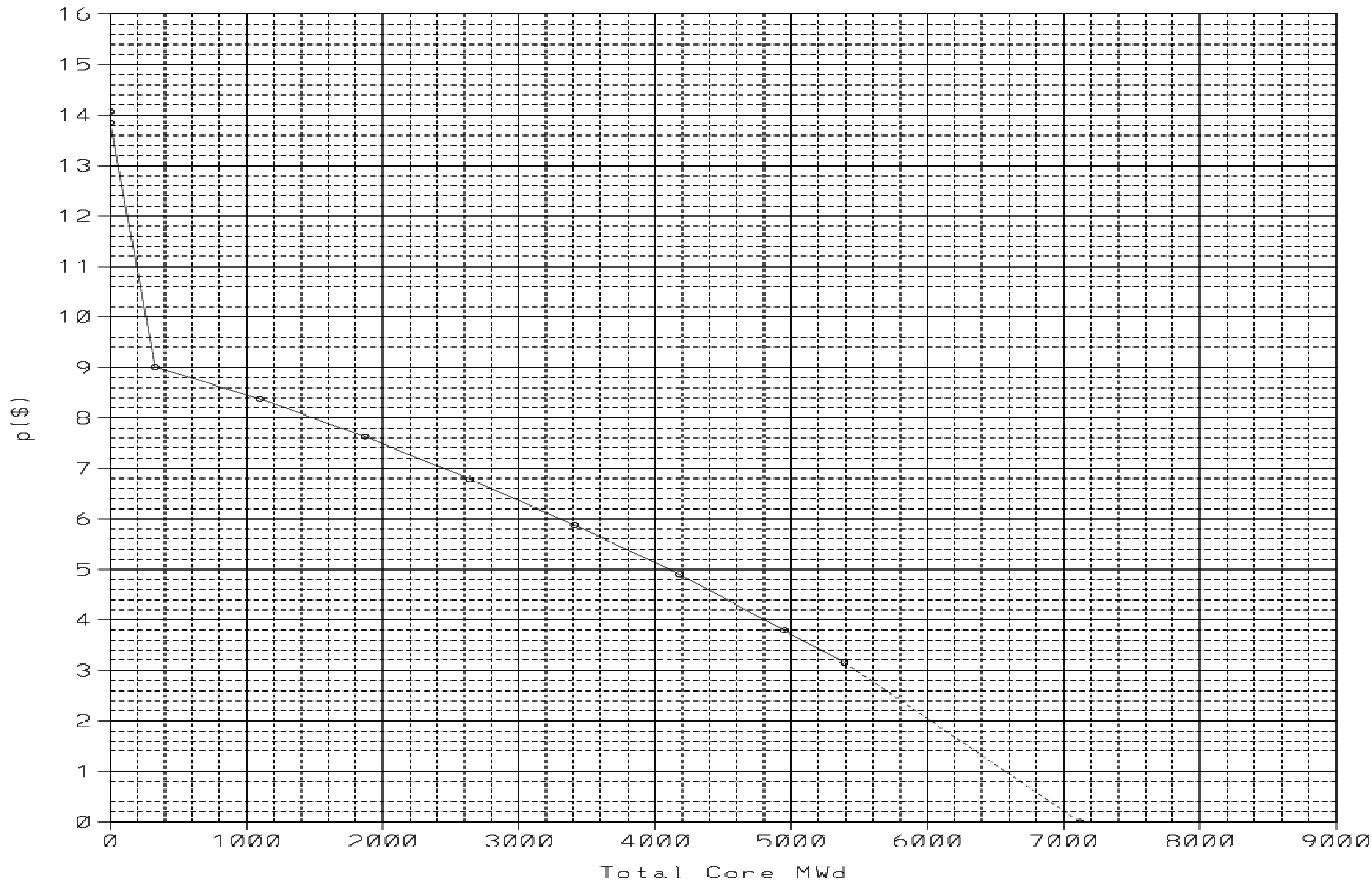

Figure A2. Estimated Total Core Excess Reactivity During ATR Cycle 147A-1