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Engineering Calculations and Analysis

ECAR Title: Results of Reactor Physics Safety Analysis for Advanced Test Reactor Cycle 151A

ECAR No.: 1742

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1. Confirmation of completeness, mathematical accuracy, and correctness of data and appropriateness of assumptions.
2. Concurrence of method or approach. See definition, LWP-10106.
3. Concurrence of procedure compliance. Concurrence with method/approach and conclusion.
4. Concurrence with the document's assumptions and input information. See definition of Acceptance, LWP-10200.

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REVISION LOG

Rev.	Date	Affected Pages	Revision Description
0	11/28/11	All	Create
1	12/8/11	7-10, and 16	ATR Complex USQ-2010-497 establishes new interim limits on EPP's. This revision updates Tables 1-5 with the new interim limits per ATR Complex USQ-2010-497.

Title: Results of Reactor Physics Safety Analysis for Advanced Test Reactor Cycle 151A

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1. Quality Level (QL) No.	1	**Professional Engineer's Stamp** NA
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8. 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.

The purpose of this revision is to update the interim limits set for EPP. Tables 1 through 5 of this revision have been updated with the new EPP limits as specified in ATR Technical Safety Requirements 3.6.1(a) (Table 3.6.1-1), and modified in Reference 13 (ATR Complex-USQ-210-497, Revision 1.

9. Conclusions/Recommendations:

Cycle 151A will run at a total core power of 101 MW for a nominal 53 days. Attached are the reactor physics data in support of the ATR Core Safety Assurance Program for Cycle 151A. The physics analysis contained herein was performed using a total core power of 100 MW with a fuel loading for 53 days. The results of the calculation show that none of the SAR/TSR limits will be violated during cycle 151A when in 2-PCP operation.

CONTENTS

APPENDIXES

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

Computer type:

UNIX Workstation (Castalia) See References 12 and 13 of Appendix A

A. Computer program name and revision: See Appendix A

B. Inputs: See Appendix A

C. Outputs: See Appendix A

D. Evidence of, or reference to, computer program validation: See Appendix A

E. Bases supporting application of the computer program to the specific physical problem: See Appendix A

DISCUSSION/ANALYSIS

See Appendix A

RECOMMENDATIONS

See Appendix A

REFERENCES

See Appendix A

Appendix A

Results of Reactor Physics Safety Analysis for Advanced Test Reactor (ATR) Cycle 151A

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.

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 151A was run for 53 days (Ref. 5) using a nominal lobe power (MW) division of 19-13-22-23-23 (NW-NE-CR-SW-SE) for a total reactor power of 100 MW. Effective plate power (EPP) values have been computed using maximum lobe powers (MW) of 19-16-30-26-26 (NW-NE-CR-SW-SE) for normalization (Ref. 6). Loop experiments (Ref. 5) included in the PDQ model used for this calculation are shown in Table A1, along with lobe nominal, minimum, and maximum powers (Ref. 6).

Data

The Cycle 151A fuel charge consists of the following fuel elements:

16 New 7F elements	15 recycle 7F elements
4 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. 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.

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 151A. 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.

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 13 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	340	330	F-32	5	100	0	210
NE	340	330	F-2	5	100	0	179
CR	340	330	F-21	5	100	3	261
SW	340	330	F-22	5	100	0	250
SE	340	330	F-19	5	100	0	243

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	340	330	F-31	5	100	3	214
NE	340	330	F-10	5	100	3	203
SW	340	330	F-21	5	100	3	261
SE	340	330	F-20	5	100	3	252

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 13 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	340	332	F-33	19	100	0	180
NE	340	332	F-8	19	100	0	155
CR	340	332	F-20	19	100	24	136
SW	340	332	F-23	19	100	0	212
SE	340	332	F-18	19	100	0	209

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

The most limiting EPP values calculated for Cycle 151A 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 151A Most Limiting EPP
19	340	23	19	100	0	212
Inner	340	22	5	100	0	250
19	340	18,23	19	100	3	196
Inner	340	21	5	100	3	261
19	340	18,23	19	100	10	193
Inner	340	21	5	100	10	258
19	340	18	19	100	17	191

Inner	340	21	5	100	17	254
19	340	18	19	100	24	188
Inner	340	21	5	100	24	246
19	340	23	19	100	31	183
Inner	340	21	5	100	31	238
19	340	18	19	100	38	178
Inner	340	21	5	100	38	227
19	340	18	19	100	45	171
Inner	340	19	5	100	45	213
19	340	18	19	100	52	164
Inner	340	19	5	100	52	207
19	340	18	19	100	53	162
Inner	340	19	5	100	53	204

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 13 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 151A 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	331	321	180	24	15	53	100
SW/Plate 19	291	266	166	24	19	3	100
SE/Inner Plates	331	321	182	17	15	53	100
SE/Plate 19	291	266	166	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 1.5×10^{21}

Days	Position Numbers
0	4, 5, 6, 7, 10, 40
3	1, 4, 5, 6, 7, 9, 10, 31, 40
10	1, 4, 5, 6, 7, 9, 10, 11, 20, 30, 31, 40
17	1, 4, 5, 6, 7, 9, 10, 11, 20, 21, 30, 31, 40
24	1, 4, 5, 6, 7, 9, 10, 11, 20, 21, 30, 31, 40
31	1, 3, 4, 5, 6, 7, 9, 10, 11, 20, 21, 30, 31, 40
38	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 20, 21, 30, 31, 40
45	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 20, 21, 25, 30, 31, 40
52	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 15, 20, 21, 25, 30, 31, 40
53	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 15, 20, 21, 25, 30, 31, 40

Once an element exceeds 1.5×10^{21} fission density, its effective point power must not exceed the appropriate limit for its position as defined in Reference 4. Tables 7 and 8 identify the calculated effective point power for the most limiting element in each lobe for an inner plate and plate 19. Lobes with "NA" entries do not have any elements that exceed 1.5 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 151A Most Limiting Effective Point Power By Lobe				
	2 PCP	3 PCP	Pos.	Plate	Restricted to (%) of limit	Days	EPtP
NW	446	465	N/A	N/A	100	N/A	N/A
NE	446	465	F-9	5	100	3	200
CR	446	465	F-20	5	100	10	303
SW	435	453	F-25	15	100	45	172
SE	435	453	F-15	15	100	52,53	183

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 151A Most Limiting Effective Point Power By Lobe				
	2 PCP	3 PCP	Pos.	Plate	Restricted to (%) of limit	Days	EPtP
NW	411	428	N/A	N/A	N/A	N/A	N/A
NE	411	428	F-2	19	100	45	156
CR	411	428	F-20	19	100	24	159
SW	411	428	F-25	19	100	45,53	134
SE	411	428	F-15	19	100	53	144

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

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

Lobe	Cycle Maximum LOBE Power (MW)	Maximum Unbalanced LOBE Power (MW)	Type of Position, Type of Plate	Limiting EPP at Maximum Unbalanced LOBE Power (MW)	Position	Plate	Restriction	Transient Effective Plate Power Limits and Overpower Ratios (MW)	Reference Lobe Power for Quadrant ΔT Setpoints (MW)
NW	19.0	35.31	All, inner plates	288	F-37	17	1.00	659/1.45 = 454	55.6*
			All, plate 19	287	F-37	19	1.00	659/1.45 = 454	55.8
NE	16.0	23.71	All, inner plates	172	F-3	15	1.00	659/1.45 = 454	62.5*
			All, plate 19	160	F-3	19	1.00	659/1.45 = 454	67.2
C	30.0	30.00	All, inner plates	206	F-21	5	1.00	659/1.45 = 454	66.1*
			All, plate 19	124	F-21	19	1.00	659/1.45 = 454	109.8
SW	26.0	37.70	All, inner plates	283	F-26	15	1.00	659/1.45 = 454	60.4
			All, plate 19	275	F-26	19	1.00	659/1.45 = 454	62.2
			< 2σ, inner plates	283	F-26	15	1.00	641/1.45 = 442	58.8
			< 2σ, plate 19	275	F-26	19	1.00	490/1.37 = 357	48.9*

SE	26.0	38.57	All, inner plates	289	F-16	15	1.00	659/1.45 = 454	60.5
			All, plate 19	281	F-16	19	1.00	659/1.45 = 454	62.3
			< 2σ, inner plates	289	F-16	15	1.00	641/1.45 = 442	58.9
			< 2σ, plate 19	281	F-16	19	1.00	490/1.37 = 357	49.0*

*indicates the minimum value for that lobe

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

Table A9 lists the fuel element powers for each time step of the cycle. In order to find the maximum expected fuel element power for the cycle, the element powers in Table A9 are scaled to the lobe maximum power by multiplying by the ratio of the lobe maximum power divided by the actual lobe power. After examining all of the scaled fuel element powers for time steps beyond xenon equilibrium, we find that the maximum expected fuel element power during Cycle 151A is 4.541 MW in core position F-21.

The maximum calculated point-to-average power density ratio at a distance 90% from the edge of the fuel in plate 19 for any element is 2.70 in position F-23 for the time step 0.

The preliminary startup power division normalized to a total core power of 250 MW is: 46.8-34.7-62.3-53.7-52.4 (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	1239	65.2	2012	105.8
NE	1086	83.5	944	59.0
C	---	---	1316	43.8

SW	1578	68.6	2060	79.2
SE	1581	68.7	2046	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 19-13-22-23-23 (NW-NE-CR-SW-SE).

c. The Time in Cycle is based on the maximum power division of 19-16-30-26-26 (NW-NE-CR-SW-SE).

The results above show sufficient reactivity to sustain the requested lobe power for the cycle length of 53 days. The results also show that the fission density limits should not be exceeded for a cycle length of 53 days in every lobe except the center (CR) lobe. The time in the cycle required to reach the CR lobe fission density limit was calculated using a maximum lobe power of 30 MW. To achieve the fission density limit during a 53 day cycle, a CR lobe average power of approximately 25 MW would have to be sustained. Calculations indicate that the CR lobe average power over the entire cycle will be 21.7 MW; Therefore, exceeding the fission density limit in the CR lobe is considered improbable. Nuclear Engineering will track actual CR Lobe MWds to ensure fission density limits in the CR Lobe are not exceeded during the cycle. The reactivity and fission density data are shown in Figures A1 and A2.

All of the elements in the fuel loading for Cycle 151A are expected to have further recycle potential after the nominal operation of Cycle 151A except for the following:

Pos.	Serial No.
5	XA755R
20	XA880T
30	YA506TM
31	XA868T

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

Hardware and Software

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

Table 11. Computer Codes and V&V Tracking Numbers

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

rzpgm	1	34117	114953
rzread	-	43442	114954
Trnf	1	2014	114957
updatr	1	25709	114958

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12. Roth, P. A., Verification and Validation of ATR Physics Analysis Software, rzpgm and rzread, on Workstation Castalia, ECAR-593, April 29, 2009.
13. ATR Complex-USQ-2010-497, Revision 1, Seismic-Induced Experiment Loop Leakage, December 5, 2011.

Table A1. Experimental Designations and Nominal Power Division for ATR Cycle 151A[5,6]

Lobe	Power	Loop Experiments
NW	+0 19 -4	2E/NW-160 R#2E
N	-	1D/N-105 Var Flux/Temp Corr. R#0
NE	+3 13 -2	AGR 3/4
W	-	1C/W-75 Med. Corr. R#0
C	+1.4 22 -4	AFIP-6 Mk-II

E	-	7-Pin Flux Trap Irradiation Facility with LSA Cobalt in E-1 through E-7
	+3	
SW	23	2D/SW-185 STD BU R#1
	-3	
S	-	AGC-2
	+3	
SE	23	2B/SE-191 STD BU R#1
	-3	

Table A2. Summary of Fuel Load for Cycle 151A

Core Pos.	Serial No.	Content ^{235}U	^{10}B	Total MWD	Irradiation History Cycle	Pos.	Cycle	Pos.	Cycle	Pos.	Cycle	Pos
1	XA726T	765	0.058	2204	145A-1	6	143A-1	13				
2	XA924T	869	0.138	1231	149B-1	13						
3	XA816T	843	0.128	1232	149B-1	22						

4	YA501TM	702	0.034	2154	145B-1	26	141A-1	12
5	XA755R	684	0.031	2215	149A-1	40	124A-1	22
6	YA504TM	653	0.021	2321	148A-1	21	135B-1	17
7	YA553TM	695	0.033	1985	149B-1	9	145B-1	7
8	XA327T	866	0.147	1170	136A-1	22	134A-1	26
9	XA130T	779	0.065	2033	134B-1	35	131A-1	17
10	XA645T	765	0.055	1941	142A-1	17	140A-1	3
11	YA515TM	764	0.062	1943	139A-1	35	135C-1	15
12	XA016U	1075	0.660					
13	XA017U	1075	0.660					
14	XA947T	1075	0.660					
15	XA894T	954	0.273	663	149A-1	8		
16	XA948T	1075	0.660					
17	XA011U	1075	0.660					
18	XA012U	1075	0.660					
19	XA014U	1075	0.660					
20	XA880T	800	0.078	1703	149A-1	16	148A-1	33
21	XA875T	808	0.086	1821	149B-1	5	148A-1	3
22	XA019U	1075	0.660					
23	XA020U	1075	0.660					
24	XA023U	1075	0.660					
25	XA831T	940	0.253	965	149B-1	7		
26	XA024U	1075	0.660					
27	XA026U	1075	0.660					

28	XA950T	1075	0.660					
29	XA951T	1075	0.660					
30	YA506TM	760	0.068	1969	143B-1	34	142B-1	7
31	XA868T	754	0.051	1831	148B-1	33	146B-1	28
32	XA746TNB	1075	0.000					
33	XA747TNB	1075	0.000					
34	XA010U	1075	0.660					
35	XA865T	892	0.167	1094	148A-1	13		
36	XA861T	903	0.185	965	149B-1	8		
37	XA748TNB	1075	0.000					
38	XA749TNB	1075	0.000					
39	XA009U	1075	0.660					
40	XA885T	753	0.050	1949	148B-1	38	146B-1	38

Table A3. Plate Restrictions for Fuel Loaded in Cycle 151A[9,10]

Core Pos.	Serial No.	Restriction	Restricted Plates (of those represented in the PDQ model)
1	XA726T		
2	XA924T		
3	XA816T		
4	YA501TM		
5	XA755R		
6	YA504TM		
7	YA553TM		
8	XA327T		
9	XA130T		
10	XA645T		
11	YA515TM		
12	XA016U		
13	XA017U		
14	XA947T		
15	XA894T		
16	XA948T		
17	XA011U		
18	XA012U		
19	XA014U		
20	XA880T		
21	XA875T		

22	XA019U
23	XA020U
24	XA023U
25	XA831T
26	XA024U
27	XA026U
28	XA950T
29	XA951T
30	YA506TM
31	XA868T
32	XA746TNB
33	XA747TNB
34	XA010U
35	XA865T
36	XA861T
37	XA748TNB
38	XA749TNB
39	XA009U
40	XA885T

Table A4. Capsule Facility Loading Used in ATR Cycle 151A Analysis[5]

Facility	Description	Reference
NEFT	AGR-3/4	SBG-05-11

CFT	AFIP-6 Mk II	HWG-03-11
E-1	LSA Cobalt	
E-2	LSA Cobalt	
E-3	LSA Cobalt	
E-4	LSA Cobalt	
E-5	LSA Cobalt	
E-6	LSA Cobalt	
E-7	LSA Cobalt	
SFT	AGC-2	MED-01-11
A-1	HSA Cobalt	BJH-2-92
A-2	HSA Cobalt	BJH-2-92
A-3	IASFR	
A-4	HSA Cobalt	BJH-2-92
A-5	HSA Cobalt	BJH-2-92
A-6	HSA Cobalt	BJH-2-92
A-7	HSA Cobalt	BJH-2-92
A-8	HSA Cobalt	BJH-2-92
A-9	HSA Cobalt	RAK-04-02
A-10	AFC-3A	KEB-13-11
A-11	AFC-3B	KEB-13-11
A-12	SFROP	

A-13	LSFR	
A-14	EPRI –ZG-B	GWW-09-11
A-15	EPRI –ZG-C	GWW-09-11
A-16	EPRI –ZG-A	GWW-09-11
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	Dwg. 600271

Table A4. Continued

Facility	Description	Reference
B-8	YSFR	
B-9	RERTR-12-4	GNH-05-11
B-10	RERTR-13-1	GNH-09-11
B-11	Aluminum Filler	
B-12	AGR-2	SBG-01-11, Rev.1
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	Beryllium Filler	
I-22	UCSB-2	TLM-1-11
I-23	LWRS-1	KEB-13-11
I-24	Aluminum Filler	

Table A5. Summary of ATR Shim Positions for ATR Cycle 151A

	NW LOBE		NE LOBE		SW LOBE		SE LOBE	
Time At Power (Days)	Outer Shims (Deg.)	Neck Shims Inserted	Outer Shims (Deg.)	Neck Shims Inserted	Outer Shims (Deg.)	Neck Shims Inserted	Outer Shims (Deg.)	Neck Shims Inserted
0	40.1	1 2 3 4 5 6	40.1	1 2 3 4 5 6	40.1	1 2 3 5 6	40.1	1 2 3 5 6
0	40.1	1 2 3 4 5 6	13.5	1 2 3 4 5 6	51.2	1 2 3 5 6	56.6	1 2 3 5 6
3	79.3	1 2 3 4 5 6	56.6	1 2 3 4 5 6	85.4	1 2 3 5	85.4	1 2 3
10	85.4	1 2 3 4 5 6	61.0	1 2 3 4 5 6	85.4	1 2 3	85.4	1 2
17	85.4	1 2 3 4 5	64.7	1 2 3 4 5 6	85.4	1 2	85.4	1
24	85.4	1 2 3 4	69.7	1 2 3 4 5 6	85.4	1	85.4	
31	85.4	1 2 3	75.2	1 2 3 4 5 6	85.4		89.8	
38	85.4	1 2	79.3	1 2 3 4 5 6	89.8		89.8	
45	85.4		85.4	1 2 3 4 5	95.2		95.2	
52	89.8		85.4	1 2 3 4	100.1		100.1	
53	95.2		85.4	1 2 3	104.2		104.2	

Table A6. Summary of ATR Core Power and Calculated $K_{effective}$ for ATR Cycle 151A

Time at Power (Days)	Total Core Power (MW)	Lobe Powers (MW) NW	NE	CR	SW	SE	$K_{effective}$
0	100	18.7	13.9	24.9	21.5	21.0	0.9889
0	100	17.6	12.1	24.3	22.6	23.3	0.9947
3	100	18.2	12.0	21.7	23.9	24.1	0.9949
10	100	18.2	12.2	21.6	24.0	24.1	0.9964
17	100	18.0	12.1	21.7	24.1	24.1	0.9992
24	100	18.0	12.2	22.0	24.0	23.9	1.0024
31	100	17.8	12.2	21.9	23.8	24.2	1.0031
38	100	18.0	12.3	21.6	24.4	23.7	1.0002
45	100	17.9	12.7	21.6	24.2	23.6	1.0016
52	100	17.9	12.9	21.1	24.3	23.8	0.9986
53	100	18.1	13.0	20.9	24.1	23.8	1.0019

Table A7. Summary of ATR Shim Positions for ATR Cycle 151A 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	40.1	1 1 1 1 1 1	40.1	1 1 1 0 1 1	0.0	1 1 1 0 1 1
NE	40.1	1 1 1 1 1 1	153.9	1 1 1 1 1 1	0.0	1 1 1 0 1 1	40.1	1 1 1 0 1 0
CR	0.0	0 0 0 0 0 0	0.0	0 0 0 0 0 0	0.0	0 0 0 0 0 0	0.0	0 0 0 0 0 0
SW	40.1	1 1 1 1 1 1	0.0	1 1 1 1 1 1	153.9	1 1 1 0 1 1	40.1	1 1 1 0 1 1
SE	0.0	1 1 1 1 1 1	40.1	1 1 1 1 1 1	40.1	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	100	35.3189	12.3059	22.0938	17.4208	12.8607	1.015048
NE	100	17.6786	23.7136	23.6274	15.6435	19.3368	0.999689
CR	100	18.3040	14.5342	30.0015	18.7445	18.4158	1.031456
SW	100	15.0899	8.9109	21.6732	37.7071	16.6190	1.022307
SE	100	11.2018	11.6536	21.6888	16.8826	38.5732	1.022219

Table A9. Summary of Fuel Element Powers for ATR Cycle 151A

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	100	2.8	2.5	2.2	1.3	0.9	0.9	1.3	2.2	2.5	2.9
0	100	2.7	2.4	1.9	1.0	0.7	0.7	1.0	2.0	2.4	2.8
3	100	2.3	2.1	1.8	1.2	0.9	0.8	1.2	2.0	2.1	2.5
10	100	2.3	2.1	1.8	1.2	0.9	0.9	1.2	2.0	2.1	2.4
17	100	2.3	2.0	1.8	1.2	0.9	0.9	1.2	2.0	2.1	2.4
24	100	2.2	2.0	1.8	1.2	0.9	0.9	1.2	2.0	2.0	2.4
31	100	2.2	2.0	1.8	1.2	1.0	1.0	1.3	2.0	2.0	2.4
38	100	2.2	2.0	1.8	1.2	1.0	1.0	1.3	2.0	2.0	2.3
45	100	2.2	2.1	1.9	1.3	1.1	1.1	1.3	2.0	2.0	2.3
52	100	2.2	2.1	1.9	1.3	1.1	1.1	1.3	2.0	2.1	2.3
53	100	2.2	2.2	1.9	1.3	1.1	1.1	1.3	2.0	2.1	2.3

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	100	3.1	3.1	2.9	2.3	1.8	1.9	2.4	3.1	3.4	3.4

0	100	3.0	3.2	3.1	2.7	2.2	2.4	2.8	3.4	3.6	3.4
3	100	2.8	3.0	3.1	2.8	2.7	2.8	3.0	3.4	3.4	3.1
10	100	2.8	3.1	3.1	2.8	2.6	2.8	2.9	3.4	3.4	3.2
17	100	2.8	3.1	3.1	2.8	2.6	2.7	2.9	3.4	3.5	3.3
24	100	2.9	3.1	3.0	2.8	2.6	2.7	2.9	3.4	3.5	3.3
31	100	2.8	3.1	3.1	2.8	2.6	2.8	3.0	3.4	3.5	3.3
38	100	2.8	3.0	3.0	2.8	2.6	2.7	2.9	3.3	3.4	3.2
45	100	2.7	2.9	3.0	2.8	2.6	2.8	2.9	3.3	3.3	3.1
52	100	2.6	2.9	3.0	2.8	2.7	2.9	3.0	3.3	3.3	3.0
53	100	2.6	2.9	3.0	2.9	2.7	2.9	3.0	3.3	3.2	2.9

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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	100	3.5	3.4	3.2	2.4	1.9	1.9	2.4	3.0	3.3	3.2
0	100	3.5	3.5	3.3	2.6	2.1	2.2	2.6	3.1	3.3	3.1
3	100	3.1	3.2	3.3	2.9	2.7	2.7	2.8	3.1	3.1	2.8
10	100	3.1	3.3	3.4	2.9	2.6	2.7	2.8	3.1	3.2	2.8
17	100	3.2	3.3	3.4	2.9	2.6	2.7	2.8	3.1	3.2	2.8
24	100	3.3	3.4	3.4	2.9	2.6	2.7	2.8	3.1	3.2	2.9
31	100	3.3	3.4	3.3	2.9	2.5	2.6	2.8	3.1	3.2	2.9
38	100	3.3	3.3	3.4	3.0	2.7	2.8	2.9	3.2	3.3	2.9
45	100	3.1	3.3	3.3	3.0	2.7	2.8	2.9	3.1	3.2	2.8
52	100	3.0	3.2	3.3	3.0	2.7	2.9	2.9	3.1	3.1	2.8
53	100	3.0	3.2	3.3	3.0	2.7	2.9	2.9	3.1	3.1	2.7

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	100	3.1	3.4	2.9	1.9	1.3	1.3	2.0	2.8	3.1	2.9
0	100	3.0	3.2	2.8	1.8	1.2	1.3	1.9	2.6	2.9	2.8

3	100	2.6	2.9	2.7	2.0	1.7	1.7	2.1	2.6	2.6	2.4
10	100	2.6	2.8	2.7	2.0	1.7	1.7	2.1	2.5	2.5	2.4
17	100	2.6	2.8	2.6	2.0	1.7	1.7	2.1	2.5	2.6	2.4
24	100	2.6	2.9	2.6	2.0	1.7	1.7	2.0	2.5	2.7	2.4
31	100	2.6	2.9	2.6	2.0	1.6	1.6	2.0	2.4	2.7	2.4
38	100	2.6	3.0	2.6	2.0	1.6	1.6	2.0	2.4	2.7	2.4
45	100	2.7	3.0	2.6	2.0	1.6	1.6	2.0	2.4	2.8	2.5
52	100	2.7	2.9	2.5	2.0	1.6	1.7	2.0	2.4	2.8	2.5
53	100	2.6	2.9	2.5	2.0	1.7	1.7	2.1	2.4	2.8	2.5

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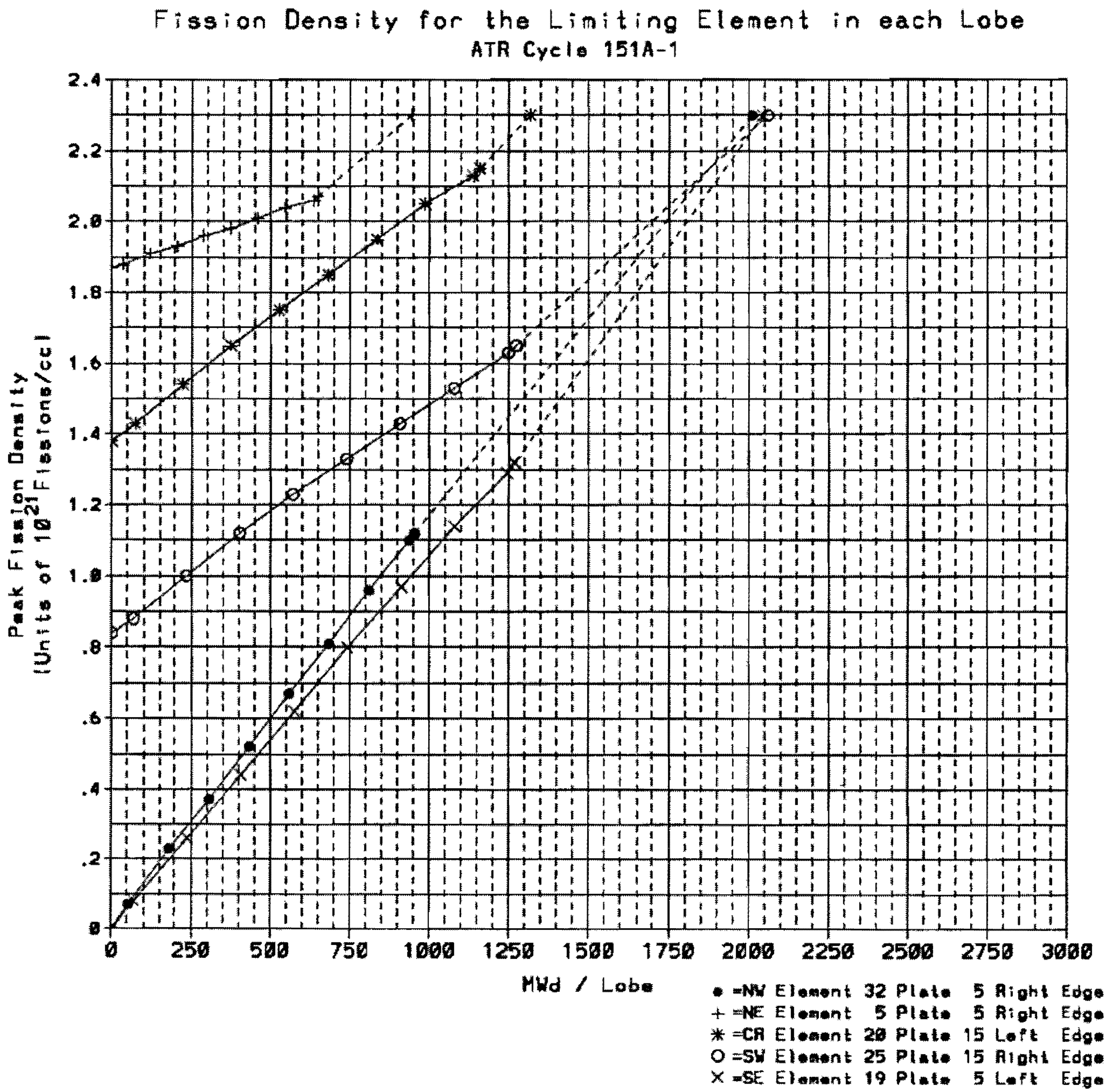

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