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ECAR-2151Results Of Reactor Physics Safety Analysis For Advanced Test Reactor Cycle 153A-1

March 2012

Changing the World's Energy Future

Mitchell A Plummer

Idaho National Laboratory

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ENGINEERING CALCULATIONS AND ANALYSIS

Title: Results of Reactor Physics Safety Analysis for Advanced Test Reactor Cycle 153A-1

ECAR No.: 2151 Rev. No.: 0 Project No.: N/A Date: 1/31/2013

1. Quality Level (QL) No.	1	**Professional Engineer's Stamp** See LWP-10010 for requirements.
2. QL Determination No.	RTC-000088	
3. Engineering Job (EJ) No.	N/A	
4. SSC ID	N/A	
5. Building	N/A	
6. Site Area	533	

7. Objective/Purpose:

The Advanced Test Reactor (ATR) Safety Analysis Report (SAR-153) 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 for Cycle 153A-1 reported in this Engineering Calculations and Analysis Report (ECAR) were obtained using the PDQWS X-Y model of the ATR core.

8. If revision, please state the reason and list sections and/or pages being affected:

9. Conclusions/Recommendations:

Attached are the reactor physics data in support of the ATR Core Safety Assurance Package for Cycle 153A-1. The physics analysis contained herein was performed using a total core power of 187 MW for a nominal 1 day and 172 MW for the remaining days using a nominal 14 day fuel loading. The results of the calculation show that SAR/TSR limits on effective plate power (EPP) will be exceeded during Cycle 153A-1 when operating with three primary coolant pumps (3-PCP operation) in the center (C), southwest (SW), and southeast (SE) lobes. A reduction in the maximum requested lobe power for those lobes is required. Allowable maximum powers for the C, SW, and SE lobes are 44.8, 54.9, and 58.4 MW, respectively.

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APPENDIXES

Title: Results of Reactor Physics Safety Analysis for Advanced Test Reactor Cycle 153A-1

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PROJECT ROLES AND RESPONSIBILITIES

Project Role	Name (Typed)	Organization	Pages covered (if applicable)
Performer	J. E. Poling	W414	
Checker[a]	M. R. Holtz	W414	
Independent Reviewer[b]	N/A	N/A	
CUI Reviewer[c]	R. A. Jordan	W414	
Manager[d]	R. A. Jordan	W414	
Requestor[e]	N/A	N/A	
Nuclear Safety[e]	A. W. LaPorta	W414	
Document Owner[e]	R. A. Jordan	W414	

Responsibilities:

a. Confirmation of completeness, mathematical accuracy, and correctness of data and appropriateness of assumptions.

b. Concurrence of method or approach. See definition, LWP-10106.

c. Concurrence with the document's markings in accordance with LWP-11202.

d. Concurrence of procedure compliance. Concurrence with method/approach and conclusion.

e. Concurrence with the document's assumptions and input information. See definition of Acceptance, LWP-10200.

NOTE: *Delete or mark "N/A" for project roles not engaged. Include ALL personnel and their roles listed above in the eCR system. The list of the roles above is not all inclusive. If needed, the list can be extended or reduced.*

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SCOPE AND BRIEF DESCRIPTION

Safety Analysis Report (SAR) -153 for the Advanced Test Reactor (ATR) requires that a reactor physics safety analysis be performed to evaluate each ATR cycle. The results for Cycle 153A-1 reported in this Engineering Calculations and Analysis Report (ECAR) were obtained using the PDQWS X-Y model of the ATR core. Reference 1 identifies a SAR-153 commitment to use the PDQWS X-Y model for the required physics safety analysis.

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. Guidance for performing and documenting the analysis is contained in the Technical Support Guide for the ATR physics model.

ASSUMPTIONS

See Appendix.

COMPUTER CODE VALIDATION

A. Computer type: UNIX Workstation (Castalia) see References 7 and 8

B. Operating System and Version: See Appendix A

C. Computer program name and revision: See Table 11

D. Inputs: See Appendix A

E. Outputs: See Appendix A

F. Evidence of, or reference to, computer program validation: See Table 11

G. Bases supporting application of the computer program to the specific physical problem: See Reference 9

H. Validation of Mathcad and spreadsheet-type software can be done by random hand calculation checks performed by the checker (See LWP-10200, Appendix E).

DISCUSSION/ANALYSIS

See Appendix.

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. R. T. McCracken letter to J. D. Abrashoff, RTMc-18-98, Determination Of Corner Lobe Powers For Quadrant Differential Temperature Setting, June 3, 1998.

3. S. W. Monk letter to A. W. LaPorta, SWM-14-12, Rev. 2, Advanced Test Reactor Cycle 153A Preliminary Experiment Requirements Letter, Revision 2, January 30, 2013

4. R. A. Jordan letter to ATR Cycle Reference Document 15, RAJ-01-13 Rev. 1, Requested Lobe Powers for Advanced Test Reactor (ATR) Cycle 153A-1 Startup, Revision 1, January 31, 2013.

5. 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.

6. 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.

7. P. A. Roth, Verification and Validation of ATR Physics Analysis Software on Workstation Castalia, ECAR-516, February, 2009.

8. Roth, P. A., Verification and Validation of ATR Physics Analysis Software, rzpgm and rzread, on Workstation Castalia, ECAR-593, April 29, 2009.

9. SAR-153, Updated Final Safety Analysis for the Advanced Test Reactor, Revision 35, January 23, 2013

10. TSR-186, Technical Safety Requirements For The Advanced Test Reactor, Revision 31, January 23, 2013.

11. A. W. LaPorta, Usage of ATR Fuel Elements Exposed to an Asymmetric Axial Flux in the NW Lobe, TEV-1632, October 3, 2012.

Appendix A

Results of Reactor Physics Safety Analysis for Advanced Test Reactor (ATR) Cycle 152A

Introduction

The Advanced Test Reactor (ATR) Safety Analysis Report (SAR-153) 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 PDQWS X-Y model of the ATR core. Reference 1 identifies a SAR-153 commitment to use the PDQWS 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 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 (EPtP) and the average axial peaking factor. The EPtP 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.

PDQWS analysis of Cycle 153A-1 assumes operation for 14 days (Reference 3) using two nominal lobe power divisions associated with the High and Low stages of a PALM cycle. Day 1 assumes a High-stage nominal lobe power division of 20-20-41-50-56 MW (NW-NE-C-SW-SE) for a total reactor power of 187 MW. A Low-stage nominal lobe power division of 20-20-38-44-50 MW (NW-NE-C-SW-SE) for a total reactor power of 172 MW is assumed for remaining days in the 14 day cycle. Computation of EPP values assumes maximum lobe powers for the High stage, first day (fast cycle) of 23-23-50-58-60 MW (NW-NE-C-SW-SE) and for the Low stage, remaining days (power demand) of 23-23-50-52-58 MW (NW-NE-C-SW-SE) for normalization (Reference 4). However, exceeded EPP values dictate a reduced maximum lobe power split for the High stage/first day of 23-23-44.8-54.9-58.4 MW (NW-NE-C-SW-SE). Loop experiments (Reference 3) included in the PDQWS model used for this calculation are shown in Table A1, along with lobe nominal, minimum, and maximum powers (Reference 4).

Data

The Cycle 153A-1 fuel charge consists of the following fuel elements:

8 New 7F elements	21 recycle 7F elements
0 New NB elements	2 recycle NB elements
0 New YA elements	0 recycle YA elements
8 New YA...M elements	1 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 such that the ligament A stress level exceeds a value of two standard deviations less than the failure stress, the safety limits for the EPtP and EPP for fuel elements adjacent to ligament A of that lobe must be reduced. Stress level in ligament A is an indicator of reflector lifetime. 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. Following Cycle 152B-1, the exposure of the reflector adjacent to the NW, NE, SW, and SE lobes passed the level where the ligament A stress will exceed a value of two standard deviations less than the failure. This ECAR documents the reduction in safety limits for the NW, NE, SW, and SE lobes.

When the inspection of a new fuel element finds a reduced width in a coolant channel between fuel plates, the EPP limit for the plates adjacent to the narrow coolant channel must be reduced. The PDQWS model used in this analysis tracks the power in 11 of the 19 fuel element plates; namely plate 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 narrow coolant channel restrictions (Table A3).

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 PDQWS model was utilized to represent the performance of the reactor during normal operation of Cycle 153A-1. 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 PDQWS model was also utilized 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.

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Results and Conclusions

The PDQWS analysis tracks the EPP in plate 19 and in 10 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 EPP limit and is used in establishing acceptance criteria for the surveillance of the Lobe Power Calculation and Indication System (LPCIS) per ATR Technical Safety Requirement [TSR 3.6.1 (b)], Reference 10.

In the event that calculated EPP values exceed TSR limits, maximum lobe power is reduced. Maximum lobe powers for Cycle 153A-1 are reduced in the C, SW, and SE lobes to 44.8, 54.9, and 58.4 MW, respectively.

Table 1 shows the limits for the EPP as specified in ATR TSR 3.6.1(a) (Table 3.6.1-1) 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	417	443	F-32	5	100	1^{high}	225
NE	417	443	F-9	5	100	1^{high}	228
C	417	443	F-20	5	100	0 1^{high}	443* 443*
SW	417	443	F-23 F-22	15 5	100 100	0 1^{high}	443* 443*
SE	417	443	F-18 F-19	15 5	100 100	0 1^{high}	443* 443*

*Maximum allowable power reduced to ensure EPP limits are not exceeded

The most limiting EPP in the C, SE and SW lobes exceed the operating limit for 3 PCPs, therefore a reduction in power is necessary.

To form quadrants, the center lobe elements are relegated to the adjacent corner lobes. Table 2 shows the most limiting inner plate EPP value in each quadrant rather than in each lobe. Table 2 indicates a reduction in power is necessary.

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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	417	443	F-31	5	100	1 high	323
NE	417	443	F-10	5	100	1 high	376
SW	417	443	F-23 F-22	15 5	100 100	0 1 high	443* 443*
SE	417	443	F-20	5	100	0,1 high	443*

*Maximum allowable power reduced to ensure EPP limits are not exceeded

Table 3 shows the limits for the EPP as specified in ATR TSR 3.6.1(a) (Table 3.6.1-1) 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	417	445	F-33	19	100	1 high	177
NE	417	445	F-8	19	100	1 high	147
C	417	445	F-20	19	100	1 high	306
SW	417	445	F-23	19	100	0,1 high	445*
SE	417	445	F-18	19	100	0	437

*Maximum allowable power reduced to ensure EPP limits are not exceeded

The plate 19 most limiting EPP values for each lobe are within the allowable TSR EPP limits for 3-PCP operation with the exception of the SW lobe which indicates a reduction in power is necessary.

The most limiting EPP values calculated for Cycle 153A-1 elements at each time step are given in Table 4.

Table 4. Limiting EPP at Each Time Step

Plate Type	EPP Limit 3 PCP	Pos.	Plate	Restricted to (%) of limit	Days[a]	Cycle 153A-1 Most Limiting EPP
19	445	23	19	100	0	445*
Inner	443	18 20 23	15 5 15	100	0	443*
19	445	23	19	100	1[high]	445*
Inner	443	19 20 22	5 5 5	100	1[high]	443*
19	445	18	19	100	1[low]	419
Inner	443	19	5	100	1[low]	437
19	445	18	19	100	3	417
Inner	443	19	5	100	3	436
19	445	18	19	100	10	400
Inner	443	19	5	100	10	426
19	445	18	19	100	14	392
Inner	443	19	5	100	14	429

a – Data for the 0-day ganged outer shim case is not included.
*Maximum allowable power reduced to ensure EPP limits are not exceeded

Exposure has exceeded the value for the limiting A-ligament stress level in the NW, NE, SW, and SE lobes. Fuel elements in core positions F-34 through F-37 in the NW lobe, F-4 through F-7 in the NE lobe, 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 TSR 3.6.1(a) (Table 3.6.1-1) must be used. The most limiting EPP values for these positions are given in Table 5 along with the $<2\sigma$ limits. Note that limiting EPP values for Plate 19 are not applicable (N/A) in the SW and SE lobes due to loading of fuel type YA in $<2\sigma$ positions. Fuel type YA contains no fuel in Plate 19.

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Table 5. Limiting EPP for core positions for which Ligament A stress is <2σ to cracking

Lobe/Plate	Effective Plate Power Limit		Cycle 153A-1 Most Limiting EPP for Ligament A (<2σ) Positions by Lobe				
	2 PCP	3 PCP	EPP	Pos.	Plate	Days	Restricted to (%) of limit
NW/Inner Plates	406	431	161	34	15	1^{high}	100
NW/Plate 19	358	357	134	34	19	1^{high}	100
NE/Inner Plates	406	431	139	7	15	1^{high},1^{low}	100
NE/Plate 19	358	357	94	7	19	1^{high},1^{low}	100
SW/Inner Plates	406	431	430	24	17	1^{high}	100
SW/Plate 19	358	357	N/A	N/A	N/A	N/A	N/A
SE/Inner Plates	406	431	431*	17	15 17	0 1^{high}	100
SE/Plate 19	358	357	N/A	N/A	N/A	N/A	N/A

N/A – not applicable - all of the <2σ positions in SW and SE are filled with YA elements that have no fuel in plate 19
*Maximum allowable power reduced to ensure EPP limits are not exceeded

The elements in several positions of the fuel loading reach a fission density greater than $1.5\text{x}10^{21}$ during Cycle 153A-1. 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 SAR-153, 4.2.1 (Reference 2). Table 6 shows the positions in which the elements have exceeded the $1.5\ \text{x}10^{21}$ 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	2, 3, 4, 5, 6, 7, 8, 9, 32, 33, 34, 35, 36, 37, 38, 39
1^{high}	2, 3, 4, 5, 6, 7, 8, 9, 32, 33, 34, 35, 36, 37, 38, 39
1^{low}	2, 3, 4, 5, 6, 7, 8, 9, 32, 33, 34, 35, 36, 37, 38, 39
3	2, 3, 4, 5, 6, 7, 8, 9, 32, 33, 34, 35, 36, 37, 38, 39
10	2, 3, 4, 5, 6, 7, 8, 9, 32, 33, 34, 35, 36, 37, 38, 39
14	2, 3, 4, 5, 6, 7, 8, 9, 32, 33, 34, 35, 36, 37, 38, 39

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 2. 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 "N/A" entries do not have any elements that exceed 1.5×10^{21} fission density during the cycle.

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

Lobe	Effective Point Power Limit		Cycle 153A-1 Most Limiting Effective Point Power By Lobe				
	2 PCP	3 PCP	Pos.	Plate	Restricted to (%) of limit	Days	EPtP
NW	435	453	F-32	5	100	1^{high}	258
NE	435	453	F-9	5	100	1^{high}	260
C	446	465	N/A	N/A	N/A	N/A	N/A
SW	435	453	N/A	N/A	N/A	N/A	N/A
SE	435	453	N/A	N/A	N/A	N/A	N/A

N/A – not applicable – no positions in C, SW and SE are $>1.5 \times 10^{21}$

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

Lobe	Effective Point Power Limit		Cycle 153A-1 Most Limiting Effective Point Power By Lobe				
	2 PCP	3 PCP	Pos.	Plate	Restricted to (%) of limit	Days	EPtP
NW	411	428	F-33	19	100	1^{high}	212
NE	411	428	F-8	19	100	1^{high}	168
C	411	428	N/A	N/A	N/A	N/A	N/A
SW	411	428	N/A	N/A	N/A	N/A	N/A
SE	411	428	N/A	N/A	N/A	N/A	N/A

N/A – not applicable - all of the $<2\sigma$ positions in SW and SE are filled with YA elements that have no fuel in plate 19. No positions in C are $>1.5 \times 10^{21}$

The worst-case lobe powers equivalent to the TSR 3.6.1a, Table 3.6.1-1 EPP limits are shown in Table 9. Worst-case lobe powers are calculated by simulating a lobe power unbalance accident using maximum shim unbalances in the PDQWS model. The results are subsequently scaled to the limiting EPP.

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	23.0	30.28	All, inner plates	224	F-33	15	1.00	709/1.45 = 488	65.9
			All, plate 19	193	F-33	19	1.00	712/1.45 = 491	77.0
			< 2σ, inner plates	209	F-34	15	1.00	690/1.45 = 475	68.8
			< 2σ, plate 19	185	F-34	19	1.00	489/1.37 = 356	58.2*
NE	23.0	30.07	All, inner plates	221	F-9	5	1.00	709/1.45 = 488	66. 3*
			All, plate 19	139	F-8	19	1.00	712/1.45 = 491	106.2
			< 2σ, inner plates	168	F-7	15	1.00	690/1.45 = 475	85.0
			< 2σ, plate 19	121	F-7	19	1.00	489/1.37 = 356	88.4
C	44.8	55.87	All, inner plates	437	F-20	5	1.00	709/1.45 = 488	62.4*
			All, plate 19	278	F-20	19	1.00	712/1.45 = 491	98.7
SW	54.9	65.86	All, inner plates	525	F-24	17	1.00	709/1.45 = 488	61.2
			All, plate 19	476	F-23	19	1.00	712/1.45 = 491	67.9
			< 2σ, inner plates	525	F-24	17	1.00	690/1.45 = 475	59.5*
			< 2σ, plate 19	N/A	N/A	N/A	1.00	489/1.37 = 356	N/A
SE	58.4	71.60	All, inner plates	556	F-17	17	1.00	709/1.45 = 488	62.8
			All, plate 19	501	F-18	19	1.00	712/1.45 = 491	70.1
			< 2σ, inner plates	556	F-17	17	1.00	690/1.45 = 475	61.1*
			< 2σ, plate 19	N/A	N/A	N/A	1.00	489/1.37 = 356	N/A

*indicates the minimum value for that lobe

N/A – not applicable - all of the <2σ positions in SW and SE are filled with YA elements that have no fuel in plate 19

The resulting worst-case lobe powers are used for establishing compliance with TSR 3.1.1(a) (Table 3.1.1-1 SR#03) for the quadrant differential temperature set point. The EPP limits utilized the methods given in Reference 2. Each line in Table 9 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.

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, multiplying by the ratio of the lobe maximum power and dividing by the actual lobe power. After examining all of the scaled fuel element powers for time steps beyond xenon equilibrium, the maximum expected fuel element power during Cycle 153A-1 is 8.427 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 3.13 in core position F-18 for the time steps 0 and 1^{high}.

The preliminary startup power division normalized to a total core power of 250 MW is: 25.6-27.9-54.8-68.7-72.9 MW (NW-NE-C-SW-SE).

The reactivity estimates and the fission density limits as given in SAR-153, Section 4.2.1.2.3 are shown in Table 10.

Table 10. Reactivity Estimates and Fission Density Limits

	Reactivity Estimate[a]		Fission Density Limit (2.3×10^{21} fissions/cc)	
Lobe	**MWd**	**Time in Cycle[b] (Days)**	**MWd**	**Time in Cycle[c] (Days)**
NW	312	15.6	458	19.9
NE	748	37.4	455	19.7
C	---	---	1560	34.8
SW	1929	38.5	2350	42.8
SE	1754	31.3	2378	40.7

a. The reactivity estimates were obtained using the XSPRJ method.
b. The Time in Cycle is based on the nominal power division of 20-20-41-50-56 (NW-NE-C-SW-SE).
c. The Time in Cycle is based on the maximum power division of 23-23-44.8-54.9-58.4 (NW-NE-C-SW-SE).

The results above show sufficient reactivity to sustain the requested lobe power for the cycle length of 14 days. The results also show that the fission density limits should not be exceeded for a cycle length of 14 days. The reactivity and fission density data are shown in Figures A1 and A2.

The following elements in the fuel loading for Cycle 153A-1 are expected to have no further recycle potential after the nominal operation of Cycle 153A-1:

Core Position	Element ID
F-2	XA808T
F-3	XA119T
F-8	XA583T
F-9	XA827T
F-32	XA833T

The methods used in this analysis are found in References 5 and 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 7 and 8.

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

Table A1. Experimental Designations and Nominal Power Division for ATR Cycle 153A-1[3,4]

Lobe	Power: Fast	Power: Power Demand	Loop Experiments	
NW	20 (+3 / -3)	20 (+3 / -3)	2E/NW-100	(Attachment to B-MT(EDT)I-1555, Rev. 1)
N	-	-	1D/N-106	(ATRC-1D-N-106-00)
NE	20 (+3 / -3)	20 (+3 / -3)	23-Hole Large Irradiation Housing Assembly	
W	-	-	1C/W-75	(ATRC-1C-W-75-00)
C	41 (+3.8 / -3)	38 (+5 / -3)	EPRI-2	(DCJ-03-12)
E	-	-	7-Hole East Irradiation Housing Assembly	
SW	50 (+4.9 / -8)	44 (+8 / -8)	2D/SW-218	(ATRC-2D-SW-218-00)
S	-	-	SPICE BU	(ATRC-S-M-200-00)
SE	56 (+2.4 / -8)	50 (+8 / -8)	2B/SE-193	(ATRC-2D-SW-187-00)

Table A2. Summary of Fuel Load for Cycle 153A-1

Core	Serial	Content		Total	Irradiation History					
Pos.	No.	^{235}U	^{10}B	MWD	Cycle	Pos.	Cycle	Pos.	Cycle	Pos.
1	XA783TNB	910	0	755	150B-1	9				
2	XA808T	632	0.016	2430	145B-1	23	146B-1	20		
3	XA119T	627	0.014	2356	131B-1	22	135C-1	32	137B-1	14
					151B-1	8				
4	YA512TM	635	0.018	2531	142B-1	25	147A-1	21		
5	XA837T	638	0.017	2508	145A-1	23	147A-1	11		
6	XA730T	646	0.019	2611	143A-1	19	147A-1	16	150A-1	38
7	XA685T	648	0.018	2810	141A-1	23	143A-1	5	148B-1	31
8	XA583T	638	0.017	2860	138A-1	3	140B-1	5	148B-1	1
9	XA827T	659	0.022	2529	145A-1	13	148A-1	11		
10	XA944T	921	0.214	966	150B-1	17				
11	XA960T	923	0.216	965	150B-1	24				
12	XA991T	1075	0.660							
13	XA992T	1075	0.660							
14	YA551TM	1023	0.517							
15	YA555TM	1023	0.517							
16	YA556TM	1023	0.517							
17	YA557TM	1023	0.517							
18	XA993T	1075	0.660							
19	XA994T	1075	0.660							
20	XA782TNB	931	0.000	965	149B-1	4				
21	XA943T	927	0.223	966	150B-1	14				
22	XA987T	1075	0.660							
23	XA988T	1075	0.660							
24	YA530TM	1023	0.517							
25	YA546TM	1023	0.517							
26	YA548TM	1023	0.517							
27	YA550TM	1023	0.517							
28	XA989T	1023	0.660							
29	XA990T	1075	0.660							
30	XA926T	918	0.226	755	150B-1	2				
31	XA962T	910	0.194	965	150B-1	28				
32	XA833T	697	0.029	2468	146A-1	17	147A-1	17		
33	XA924T	698	0.032	2031	149B-1	13	151A-1	2		
34	XA696T	700	0.034	2088	142B-1	39	149A-1	1		
35	XA318T	701	0.032	1897	134A-1	17	142A-1	3	143B-1	32
36	XA841T	686	0.025	2468	146A-1	18	147A-1	15		
37	XA816T	690	0.028	2032	149B-1	22	151A-1	3		
38	XA834T	692	0.027	2429	145A-1	18	146B-1	15		
39	XA867T	694	0.037	2135	146B-1	22	149B-1	29		
40	XA917T	910	0.218	883	149A-1	22				

Title: Result of Reactor Physics Safety Analysis for Advanced Test Reactor Cycle 153A-1

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Table A3. Plate Restrictions for Fuel Loaded in Cycle 153A-1[9,10]

Core Pos.	Serial No.	Restriction	Restricted Plates (of those represented in the PDQWS model)
1	XA783TNB		
2	XA808T		
3	XA119T		
4	YA512TM		
5	XA837T		
6	XA730T		
7	XA685T		
8	XA583T		
9	XA827T		
10	XA944T		
11	XA960T		
12	XA991T		
13	XA992T		
14	YA551TM		
15	YA555TM		
16	YA556TM		
17	YA557TM		
18	XA993T		
19	XA994T		
20	XA782TNB		
21	XA943T		
22	XA987T		
23	XA988T		
24	YA530TM		
25	YA546TM		
26	YA548TM		
27	YA550TM		
28	XA989T		
29	XA990T		
30	XA926T		
31	XA962T		
32	XA833T		
33	XA924T		
34	XA696T		
35	XA318T	OK to use MBM-041-07	
36	XA841T		
37	XA816T		
38	XA834T		
39	XA867T		
40	XA917T		

Title: Result of Reactor Physics Safety Analysis for Advanced Test Reactor Cycle 153A-1

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Table A4. Capsule Facility Loading Used in ATR Cycle 153A-1 Analysis[3]

Facility	Description	Reference
A-1	IASFR	
A-2	IASFR	
A-3	IASFR	
A-4	IASFR	
A-5	IASFR	
A-6	IASFR	
A-7	IASFR	
A-8	IASFR	
A-9	SFROP	
A-10	SFROP	
A-11	SFROP	
A-12	SFROP	
A-13	LSFR	
A-14	LSFR	
A-15	LSFR	
A-16	LSFR	
B-1	LSFR	
B-2	YSFR	
B-3	YSFR	
B-4	YSFR	
B-5	YSFR	
B-6	YSFR	
B-7	HSIS Hardware	Dwg. 600271
B-8	YSFR	
B-9	Aluminum Filler	
B-10	Aluminum Filler	
B-11	Aluminum Filler	
B-12	Aluminum Filler	

Table A4. Continued

Facility	Description	Reference
H-1	Hafnium Shim	
H-2	LSA Cobalt	CSR-06-12
H-3	N-16 Monitor	
H-4	LSA Cobalt	CSR-06-12
H-5	Hafnium Shim	
H-6	LSA Cobalt	CSR-06-12
H-7	Hafnium Shim	
H-8	LSA Cobalt	CSR-06-12
H-9	Hafnium Shim	
H-10	LSA Cobalt	CSR-06-12
H-11	N-16 Monitor	
H-12	LSA Cobalt	CSR-06-12
H-13	Hafnium Shim	
H-14	LSA Cobalt	CSR-06-12
H-15	Hafnium Shim	
H-16	LSA Cobalt	CSR-06-12
I-1 thru I-20	Beryllium Filler	
I-21	Aluminum Filler	
I-22	Aluminum Filler	
I-23	Aluminum Filler	
I-24	AGR-2	BG-07-12

Title: Result of Reactor Physics Safety Analysis for Advanced Test Reactor Cycle 153A-1

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Table A5. Summary of ATR Shim Positions for ATR Cycle 153A-1

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	69.7	1 2 3 4 5 6	69.7	1 2 3 4 5 6	69.7	1 2 3 5 6	69.7	1 2 3 5 6
0	69.7	1 2 3 4 5 6	64.7	1 2 3 4 5 6	69.7	1 2 3 5 6	75.2	1 2 3 5 6
1^{high}	85.4	1 2 3 4 5	79.3	1 2 3 4 5 6	85.4	1 2	89.8	
1^{low}	85.4	1 2	85.4	1 2 3 4 5	85.4	1 2 3	89.8	
3	85.4	1 2	85.4	1 2 3 4 5	85.4	1 2 3	89.8	
10	89.8		85.4	1 2 3 4	85.4	1 2	95.2	
14	89.8		85.4	1 2 3	85.4	1	95.2	

Table A6. Summary of ATR Core Power and Calculated $K_{effective}$ for ATR Cycle 153A-1

Time At Power (Days)	Total Core Power (MW)	Lobe Powers (MW) NW	NE	C	SW	SE	$K_{effective}$
0	187	19.2	20.9	41.0	51.4	54.6	0.9948
0	187	18.6	19.9	40.6	50.4	57.4	0.9972
1^{high}	187	19.2	19.6	41.2	50.2	56.7	1.0011
1^{low}	172	18.5	19.6	38.0	44.4	51.4	1.0021
3	172	18.8	19.9	38.1	44.1	51.1	0.9993
10	172	19.0	19.5	38.2	43.9	51.4	1.0025
14	172	18.7	19.4	38.5	44.5	50.9	1.0029

Table A7. Summary of ATR Shim Positions for ATR Cycle 153A-1 Worst Case Calculations

	NW LOBE		NE LOBE		SW LOBE		SE LOBE	
Lobe	**(Deg.)**	**Inserted**	**(Deg.)**	**Inserted**	**(Deg.)**	**Inserted**	**(Deg.)**	**Inserted**
NW	153.9	1 1 1 1 0 0	79.3	1 1 1 1 1 1	85.4	1 1 0 0 0 0	0.0	0 0 0 0 0 0
NE	85.4	1 1 1 1 0 0	153.9	1 1 1 1 1 1	0.0	1 1 0 0 0 0	89.8	0 0 0 0 0 0
C	0.0	0 0 0 0 0 0	0.0	0 0 0 0 0 0	0.0	0 0 0 0 0 0	0.0	0 0 0 0 0 0
SW	85.4	1 1 1 1 0 0	0.0	1 1 1 1 1 1	153.9	1 1 0 0 0 0	89.8	0 0 0 0 0 0
SE	0.0	1 1 1 1 0 0	79.3	1 1 1 1 1 1	85.4	1 1 0 0 0 0	153.9	0 0 0 0 0 0

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**	**C**	**SW**	**SE**	**$K_{effective}$**
NW	187	30.2843	20.6720	43.2059	59.3536	33.4843	0.9840
NE	187	19.7178	30.0703	42.7211	30.2457	64.2450	0.9899
C	187	21.5986	24.2249	55.8670	41.4548	43.8547	0.9671
SW	187	18.6618	12.5334	39.4432	65.8560	50.5057	1.0142
SE	187	11.9252	18.8669	39.6281	44.9782	71.6016	1.0148

Title: Result of Reactor Physics Safety Analysis for Advanced Test Reactor Cycle 153A-1

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Table A9. Summary of Fuel Element Powers for ATR Cycle 153A-1

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	187.0	3.9	3.1	2.7	2.0	1.7	1.8	2.4	3.5	3.8	4.9
0	187.0	3.9	3.0	2.6	1.9	1.5	1.6	2.2	3.4	3.7	4.8
1^{high}	187.0	3.7	2.8	2.5	1.8	1.6	1.7	2.3	3.3	3.6	4.7
1^{low}	172.0	3.6	2.9	2.5	1.9	1.6	1.7	2.3	3.2	3.5	4.4
3	172.0	3.6	2.9	2.5	1.9	1.7	1.8	2.3	3.3	3.5	4.5
10	172.0	3.6	2.9	2.5	1.9	1.6	1.7	2.2	3.2	3.5	4.4
14	172.0	3.7	3.0	2.5	1.8	1.6	1.7	2.2	3.1	3.6	4.4

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	187.0	5.8	7.2	7.3	6.4	5.9	6.0	6.6	7.8	7.5	6.5
0	187.0	5.8	7.3	7.6	6.8	6.4	6.5	7.0	8.1	7.7	6.5
1^{high}	187.0	6.2	7.6	7.4	6.5	6.3	6.4	6.7	7.9	7.9	6.9
1^{low}	172.0	5.7	6.9	6.8	5.9	5.7	5.8	6.1	7.1	7.2	6.3
3	172.0	5.7	6.9	6.7	5.9	5.7	5.7	6.0	7.0	7.1	6.2
10	172.0	5.6	6.8	6.7	6.0	5.8	5.8	6.1	7.1	7.1	6.0
14	172.0	5.5	6.8	6.7	5.9	5.7	5.8	6.1	7.0	7.0	6.0

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	187.0	6.3	7.2	7.5	6.3	5.6	5.6	6.0	6.7	6.5	5.4
0	187.0	6.3	7.1	7.4	6.2	5.5	5.4	5.8	6.6	6.4	5.3
1^{high}	187.0	6.4	7.3	7.2	6.0	5.6	5.5	5.7	6.4	6.6	5.4
1^{low}	172.0	5.6	6.4	6.4	5.3	4.9	4.8	5.0	5.7	5.8	4.8
3	172.0	5.6	6.4	6.4	5.3	4.9	4.8	5.0	5.7	5.8	4.8
10	172.0	5.6	6.4	6.3	5.2	4.8	4.7	4.9	5.6	5.8	4.8
14	172.0	5.7	6.5	6.4	5.3	4.8	4.8	5.0	5.7	6.0	5.0

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	187.0	4.4	3.5	3.1	2.1	1.6	1.5	1.8	2.5	3.0	3.8
0	187.0	4.3	3.4	3.0	2.0	1.5	1.5	1.8	2.5	3.0	3.7
1^{high}	187.0	4.3	3.5	3.1	2.1	1.6	1.6	1.8	2.5	3.1	3.6
1^{low}	172.0	4.1	3.4	2.9	2.0	1.6	1.5	1.8	2.4	3.0	3.6
3	172.0	4.1	3.4	2.9	2.0	1.6	1.5	1.8	2.4	3.1	3.6
10	172.0	4.3	3.4	2.9	2.0	1.6	1.6	1.8	2.5	3.1	3.8
14	172.0	4.3	3.4	2.9	2.0	1.6	1.5	1.8	2.4	3.1	3.8

ENGINEERING CALCULATIONS AND ANALYSIS

Title: Result of Reactor Physics Safety Analysis for Advanced Test Reactor Cycle 153A-1

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Figure A1. Fission Density for the Limiting Element in each Lobe for ATR Cycle 153A-1

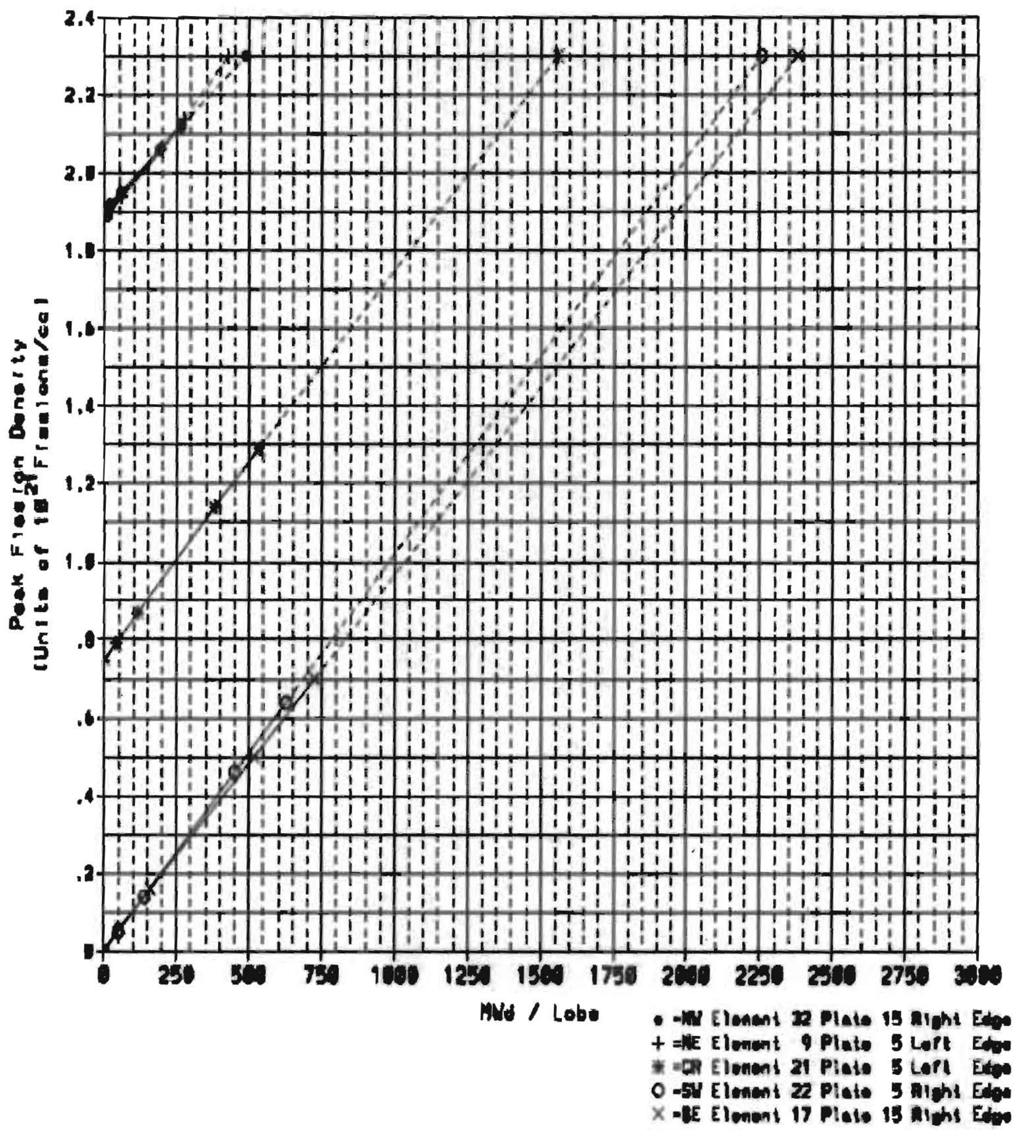

Figure A2. Estimated total core excess reactivity during ATR Cycle 153A-1