ENGINEERING CALCULATIONS AND ANALYSIS

Title: Results of Reactor Physics Safety Analysis for Advanced Test Reactor Cycle 152B-1

ECAR No.: 2080 Rev. No.: 0 Project No.: N/A Date: 11/05/2012

1. Quality Level (QL) No.	1	**Professional Engineer's Stamp**
2. QL Determination No.	RTC-000088	See LWP-10010 for requirements.
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 152B-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 152B-1. The physics analysis contained herein was performed using a total core power of 104 MW with a fuel loading for 53 days, and was scaled up to 107 MW. The results of the calculation show that none of the SAR/TSR limits will be violated during Cycle 152B-1 when operating with two primary coolant pumps (2-PCP operation).

Title: Results of Reactor Physics Safety Analysis for Advanced Test Reactor Cycle 152B-1

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APPENDIXES

Title: Results of Reactor Physics Safety Analysis for Advanced Test Reactor Cycle 152B-1

ECAR No.: 2080 Rev. No.: 0 Project No.: N/A Date: 11/05/2012

PROJECT ROLES AND RESPONSIBILITIES

Project Role	Name (Typed)	Organization	Pages covered (if applicable)
Performer	J. E. Poling	W414	
Checker[a]	P. A. Roth	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.*

Title: Results of Reactor Physics Safety Analysis for Advanced Test Reactor Cycle 152B-1

ECAR No.: 2080 Rev. No.: 0 Project No.: N/A Date: 11/05/2012

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 152B-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 10

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. C. J. Stanley letter to A. W. LaPorta, CJS-05-12, Rev.0, Advanced Test Reactor Cycle 152B Preliminary Experiment Requirements Letter, Revision 0, August 6, 2012
4. R. A. Jordan letter to ATR Cycle Reference Document 15, RAJ-10-12, Requested Lobe Powers for Advanced Test Reactor (ATR) Cycle 152B-1 Startup, October 17, 2012.
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. ATR Complex-USQ-2010-497, Revision 3, Seismic-Induced Experiment Loop Leakage, May 10, 2012.
10. SAR-153, Updated Final Safety Analysis for the Advanced Test Reactor, Revision 34, June 24, 2012
11. TSR-186, Technical Safety Requirements For The Advanced Test Reactor, Revision 29, August 11, 2012.
12. 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 152B-1 assumes operation for 53 days (Ref. 3) using a nominal lobe power (MW) division of 19-16-23-23-23 (NW-NE-C-SW-SE) for a total reactor power of 104 MW. Computation of EPP values assume maximum lobe powers (MW) of 21-18-33-26-26 (NW-NE-C-SW-SE) for normalization (Ref. 4). Loop experiments (Ref. 3) included in the PDQWS model used for this calculation are shown in Table A1, along with lobe nominal, minimum, and maximum powers (Ref. 4).

Data

The Cycle 152B-1 fuel charge consists of the following fuel elements:

13 New 7F elements	19 recycle 7F elements
0 New NB elements	1 recycle NB elements
0 New YA elements	7 recycle YA elements
0 New YA...M elements	0 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. The exposure of the reflector adjacent to the NW, 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. This ECAR documents the reduction in safety limits for the NW, 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. 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 narrow coolant channel restrictions. However, Table A3 shows that special treatment is needed for the elements in positions 9 and 25 due to TEV-1632 (Reference 12). Accordingly, the EPP values calculated for these elements have been multiplied by 1.08 and the effective point power values have been multiplied by 1.05.

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 run to represent the performance of the reactor during normal operation of Cycle 152B-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 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.

The PDQWS analysis of Cycle 152B-1 assumes a nominal lobe power division (MW) of 19-16-23-23-23 (NW-NE-C-SW-SE), for a total power of 104 MW. A change in the requested lobe power from 104 MW to 107 MW (Reference 4) resulted in a change to the EPP scaling factor. Tables 1-5 and Table A9 reflect this change. Table A9 shows the calculations were modeled at the assumed nominal lobe power (104 MW), but it should be noted that the values for fuel element powers use the updated scaling factor.

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 used in establishing acceptance criteria for the surveillance of the Lobe Power Calculation and Indication System (LPCIS), ATR Technical Safety Requirement [TSR 3.6.1 (b)].

Table 1 shows the limits for the EPP as specified in ATR TSR 3.6.1(a) (Table 3.6.1-1), and modified in Reference 9 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	202
NE	340	330	F-9	5	100	0	197*
C	340	330	F-21	5	100	0	261
SW	340	330	F-22	5	100	0	225
SE	340	330	F-19	5	100	0	225

*value adjusted per TEV-1632 (Reference 12)

The most limiting EPP in each lobe is less than the operating limit for 2 PCPs, therefore 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	234
NE	340	330	F-10	5	100	17	229
SW	340	330	F-21	5	100	0	261
SE	340	330	F-20	5	100	0	261

Table 3 shows the limits for the EPP as specified in ATR TSR 3.6.1(a) (Table 3.6.1-1), and modified in Reference 9 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	0,3	157
NE	340	332	F-8	19	100	0	143
C	340	332	F-21	19	100	0,3	165
SW	340	332	F-23	19	100	0	201
SE	340	332	F-18	19	100	0	202

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 152B-1 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 152B-1 Most Limiting EPP
19	340	18	19	100	0	202
Inner	340	21	5	100	0	261
19	340	23	19	100	3	192
Inner	340	21	5	100	3	257
19	340	23	19	100	10	191
Inner	340	20	5	100	10	257
19	340	23	19	100	17	187
Inner	340	20	5	100	17	255
19	340	23	19	100	24	185
Inner	340	20	5	100	24	255
19	340	18,23	19	100	31	180
Inner	340	20	5	100	31	252
19	340	23	19	100	38	176
Inner	340	20	5	100	38	240
19	340	23	19	100	45	173
Inner	340	21	5	100	45	239
19	340	23	19	100	52	167
Inner	340	21	5	100	52	236
19	340	23	19	100	53	167
Inner	340	21	5	100	53	235

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

Exposure has exceeded the value for the limiting A-ligament stress level in the NW, SW, and SE lobes. Core positions F-34 through F-37 in the NW 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), and modified in Reference 9 must be used. The most limiting EPP values for these positions are given in Table 5 along with the $<2\sigma$ limits.

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

Lobe/Plate	Effective Plate Power Limit		Cycle 152B-1 Most Limiting EPP for Ligament A ($<2\sigma$) Positions by Lobe				
	2 PCP	3 PCP	EPP	Pos.	Plate	Days	Restricted to (%) of limit
NW/Inner Plates	331	321	154	34	15	31	100
NW/Plate 19	291	266	110	35	19	52	100
SW/Inner Plates	331	321	174	24	15	24	100
SW/Plate 19	291	266	156	24	19	17	100
SE/Inner Plates	331	321	178	14	15	52,53	100
SE/Plate 19	291	266	159	14	19	3	100

The elements in several positions of the fuel loading for this cycle reach a fission density greater than 1.5×10^{21} during the cycle. For these elements, keeping the effective point powers less than the appropriate limits will prevent blistering of the fuel by ensuring that the maximum temperature will be at least 2σ less than 500°F (533°K) as required under SAR-153, 4.2.1 (Reference 2). Table 6 shows the positions in which the elements have exceeded the 1.5×10^{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	4, 5, 6
3	4, 5, 6
10	4, 5, 6, 7
17	3, 4, 5, 6, 7
24	1, 2, 3, 4, 5, 6, 7, 8, 10
31	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 30, 31, 40
38	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 20, 21, 30, 31, 40
45	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 20, 21, 30, 31, 40
52	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 15, 20, 21, 25, 26, 27, 30, 31, 40
53	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 15, 20, 21, 25, 26, 27, 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 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 "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 152B-1 Most Limiting Effective Point Power By Lobe				
	2 PCP	3 PCP	Pos.	Plate	Restricted to (%) of limit	Days	EPtP
NW	435	453	N/A	N/A	N/A	N/A	N/A
NE	446	465	F-9	5	100	31,38	223*
C	446	465	F-20	5	100	38	294
SW	435	453	F-27	15	100	52,53	181
SE	435	453	F-15	15	100	52	181

*value adjusted per TEV-1632 (Reference 12)

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 152B-1 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-8	19	100	24	168
C	411	428	F-21	19	100	38	177
SW	411	428	F-27	19	100	52	145
SE	411	428	F-15	19	100	52	140

The worst-case lobe powers equivalent to the TSR 3.6.1a, Table 3.6.1-1 EPP limits are shown in Table 9. The worst-cases were found by simulating a lobe power unbalance accident using maximum shim unbalances in the PDQWS model and 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	21.0	26.80	All, inner plates	203	F-34	15	1.00	659/1.45 = 454	59.9
			All, plate 19	170	F-35	19	1.00	659/1.45 = 454	71.5
			< 2σ, inner plates	203	F-34	15	1.00	641/1.45 = 442	58.3
			< 2σ, plate 19	170	F-35	19	1.00	490/1.37 = 357	56.2*
NE	18.0	26.38	All, inner plates	205	F-9	5	1.00	659/1.45 = 454	58.3*
			All, plate 19	173	F-8	19	1.00	659/1.45 = 454	69.2
C	33.0	31.45	All, inner plates	220	F-21	5	1.00	659/1.45 = 454	64.9*
			All, plate 19	158	F-21	19	1.00	659/1.45 = 454	90.3
SW	26.0	41.37	All, inner plates	328**	F-25	15	1.00	659/1.45 = 454	60.1
			All, plate 19	300**	F-25	19	1.00	659/1.45 = 454	65.6
			< 2σ, inner plates	328**	F-25	15	1.00	641/1.45 = 442	58.5
			< 2σ, plate 19	300**	F-25	19	1.00	490/1.37 = 357	49.2*
SE	26.0	39.75	All, inner plates	300	F-16	17	1.00	659/1.45 = 454	60.1
			All, plate 19	276	F-14	19	1.00	659/1.45 = 454	65.3
			< 2σ, inner plates	300	F-16	17	1.00	641/1.45 = 442	58.5
			< 2σ, plate 19	276	F-14	19	1.00	490/1.37 = 357	51.4*

*indicates the minimum value for that lobe
**value adjusted per TEV-1632 (Reference 12)

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 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 is 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, 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 152B-1 is 4.655 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 2.47 in position F-18 for the time step 0.

The preliminary startup power division normalized to a total core power of 250 MW is: 36.9-36.3-59.4-60.2-57.3 (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	1044	54.9	1692	80.5
NE	727	45.4	1162	64.5
C	---	---	1671	50.6
SW	1720	74.7	2064	79.3
SE	1605	69.7	2111	81.1

a. The reactivity estimates were obtained using the XSPRJ method.
b. The Time in Cycle is based on the nominal power division of 19-16-23-23-23 (NW-NE-C-SW-SE).
c. The Time in Cycle is based on the maximum power division of 21-18-33-26-26 (NW-NE-C-SW-SE).

The results above show sufficient reactivity to sustain the requested lobe power for the cycle length of 53 days except for the NE quadrant. It is expected that the excess reactivity in the NW, SW, and SE quadrants will compensate for the shortage of reactivity in the NE quadrant. The results also show that the fission density limits should not be exceeded for a cycle length of 53 days except in the C lobe. The time in the cycle required to reach the C lobe fission density limit was calculated using a maximum lobe power of 33 MW. To achieve the fission density limit during a 53 day cycle, a C lobe average power of approximately 31.5 MW would have to be sustained. Calculations and operational experience indicate that the C lobe average power over the entire cycle will probably be less than 24 MW. Thus, exceeding the fission density limit is considered improbable. Nuclear Engineering will track actual C Lobe MWds to ensure fission density limits in the C 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 152B-1 are expected to have further recycle potential after the nominal operation of Cycle 152B-1.

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

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Table A1. Experimental Designations and Nominal Power Division for ATR Cycle 152B-1[3,4]

Lobe	Power	Loop Experiments	
NW	19^{+2}_{-4}	2E/NW-160	(ATRC-2E-NW-160-02E)
N	-	1D/N-106	(ATRC-1D-N-106-00)
NE	16^{+2}_{-2}	AGR 3/4	(SBG-05-11)
W	-	1C/W-75	(ATRC-1C-W-75-00)
C	26^{+7}_{-6}	2A-C-BU	(DCJ-02-12)
E	-	AGC-3	(SBG-01-12)
SW	23^{+3}_{-3}	2D/SW-218	(ATRC-2D-SW-218-00)
S	-	SPICE 9	(ATRC-S-M-101-01)
SE	23^{+3}_{-3}	2B/SE-192	(ATRC-2B-SE-192-00)

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Table A2. Summary of Fuel Load for Cycle 152B-1

Core Pos.	Serial No.	Content ^{235}U	^{10}B	Total MWD	Irradiation History Cycle	Pos.	Cycle	Pos.
1	XA819T	846	0.124	1191	144B-1	19		
2	XA764TNB	831	0.000	1418	149A-1	9	150B-1	5
3	XA879T	825	0.104	1289	148A-1	32	150A-1	13
4	YA534TM	743	0.049	2070	143A-1	15	149A-1	15
5	YA538TM	715	0.038	2342	143B-1	15	146A-1	4
6	XA874T	713	0.038	2274	148A-1	19	151B-1	15
7	XA920T	798	0.078	1849	149A-1	24	150B-1	16
8	XA842T	832	0.117	1313	146A-1	19		
9	YA520TM	829	0.113	1434	150A-1	25	151B-1	37
10	XA891T	848	0.130	1157	147A-1	32		
11	XA024U	883	0.156	1324	151A-1	26		
12	XA054U	1075	0.660					
13	XA055U	1075	0.660					
14	XA056U	1075	0.660					
15	XA938T	942	0.249	755	150B-1	8		
16	YA481TM	954	0.309	433	150A-1	17		
17	XA057U	1075	0.660					
18	XA058U	1075	0.660					
19	XA059U	1075	0.660					
20	XA946T	899	0.173	966	150B-1	18		
21	XA959T	901	0.176	965	150B-1	23		
22	XA060U	1075	0.660					
23	XA063U	1075	0.660					
24	XA954T	1075	0.660					
25	XA010U	923	0.223	1059	151A-1	34		
26	XA942T	913	0.198	966	150B-1	13		
27	XA904T	926	0.240	847	149A-1	12		
28	XA967T	1075	0.660					
29	XA983T	1075	0.660					
30	XA244T	885	0.158	1185	148B-1	17		
31	XA011U	870	0.139	1289	151A-1	17		
32	XA985T	1075	0.660					
33	XA939T	969	0.315	755	150B-1	7		
34	YA490TM	950	0.298	463	150A-1	24		
35	XA863T	936	0.257	663	149A-1	2		
36	XA932T	942	0.249	755	150B-1	3		
37	YA529TM	953	0.305	463	150A-1	27		
38	YA527TM	956	0.310	463	150A-1	26		
39	XA986T	1075	0.660					
40	XA950T	854	0.122	1324	151A-1	28		

Table A3. Plate Restrictions for Fuel Loaded in Cycle 152B-1[9,10,12]

Core Pos.	Serial No.	Restriction	Restricted Plates (of those represented in the PDQWS model)
1	XA819T		
2	XA764TNB		
3	XA879T		
4	YA534TM		
5	YA538TM		
6	XA874T		
7	XA920T		
8	XA842T		
9	YA520TM	See TEV-1632	
10	XA891T		
11	XA024U		
12	XA054U		
13	XA055U		
14	XA056U		
15	XA938T		
16	YA481TM		
17	XA057U		
18	XA058U		
19	XA059U		
20	XA946T		
21	XA959T		
22	XA060U		
23	XA063U		
24	XA954T		
25	XA010U	See TEV-1632	
26	XA942T		
27	XA904T		
28	XA967T		
29	XA983T		
30	XA244T		
31	XA011U		
32	XA985T		
33	XA939T		
34	YA490TM		
35	XA863T		
36	XA932T		
37	YA529TM		
38	YA527TM		
39	XA986T		
40	XA950T		

Table A4. Capsule Facility Loading Used in ATR Cycle 152B-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	AFC-3A	KEB-26-12, Rev. 2
A-11	SFROP	
A-12	SFROP	
A-13	LSFR	
A-14	EPRI –ZG-B	GWW-10-11
A-15	EPRI –ZG-C	GWW-10-11
A-16	EPRI –ZG-A	GWW-10-11
B-1	Startup Source	RAK-03-02
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	ISU-MANTRA-1	TLM-01-12
B-10	Aluminum Filler	
B-11	ISU-MANTRA-3	TLM-01-12
B-12	AGR-2	SBG-01-11, Rev.1

Title: Result of Reactor Physics Safety Analysis for Advanced Test Reactor Cycle 152B-1

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Table A4. Continued

Facility	Description	Reference
H-1	LSA Cobalt	CSR-06-12
H-2	Aluminum Filler	
H-3	N-16 Monitor	
H-4	LSA Cobalt	CSR-06-12
H-5	LSA Cobalt	CSR-06-12
H-6	LSA Cobalt	CSR-06-12
H-7	LSA Cobalt	CSR-06-12
H-8	LSA Cobalt	CSR-06-12
H-9	LSA Cobalt	CSR-06-12
H-10	Aluminum Filler	
H-11	N-16 Monitor	
H-12	LSA Cobalt	CSR-06-12
H-13	LSA Cobalt	CSR-06-12
H-14	LSA Cobalt	CSR-06-12
H-15	LSA Cobalt	CSR-06-12
H-16	LSA Cobalt	CSR-06-12
I-1 thru I-20	Beryllium Filler	
I-21	Aluminum Filler	
I-22	UCSB-2	TLM-01-11
I-23	Aluminum Filler	
I-24	Aluminum Filler	

Title: Result of Reactor Physics Safety Analysis for Advanced Test Reactor Cycle 152B-1

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Table A5. Summary of ATR Shim Positions for ATR Cycle 152B-1

	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	56.6	1 2 3 4 5 6	56.6	1 2 3 4 5 6	56.6	1 2 3 5 6	56.6	1 2 3 5 6
0	79.3	1 2 3 4 5 6	56.6	1 2 3 4 5 6	56.6	1 2 3 5 6	61.0	1 2 3 5 6
3	89.8		85.4	1 2 3 4 5 6	79.3	1 2 3 5 6	85.4	1 2 3
10	95.2		85.4	1 2 3 4 5 6	79.3	1 2 3 5 6	85.4	1 2
17	95.2		85.4	1 2 3 4	85.4	1 2 3 5 6	85.4	1
24	100.1		85.4	1 2 3 4	85.4	1 2 3 5 6	85.4	
31	104.2		85.4	1 2 3	85.4	1 2 3 5	85.4	
38	111.7		85.4		85.4	1 2 3	89.8	
45	116.4		95.2		85.4	1	95.2	
52	134.2		111.7		89.8		104.2	
53	134.2		111.7		89.8		104.2	

Table A6. Summary of ATR Core Power and Calculated $K_{effective}$ for ATR Cycle 152B-1

Time At Power (Days)	Total Core Power (MW)	Lobe Powers (MW) NW	NE	C	SW	SE	$K_{effective}$
0	104.0	15.4	15.1	24.7	25.0	23.8	0.9854
0	104.0	17.8	14.6	24.1	24.0	23.5	0.9903
3	104.0	18.2	15.5	23.3	23.3	23.6	0.9919
10	104.0	18.6	15.2	23.2	23.1	23.9	0.9931
17	104.0	17.9	15.8	23.1	23.3	23.9	0.9976
24	104.0	18.1	15.3	23.1	23.2	24.2	0.9968
31	104.0	18.3	15.2	23.0	23.8	23.7	0.9968
38	104.0	18.3	15.6	23.5	23.1	23.5	1.0019
45	104.0	18.0	15.5	23.5	23.3	23.7	1.0028
52	104.0	18.0	15.7	23.0	23.3	24.0	1.0036
53	104.0	18.0	15.7	23.0	23.3	24.0	1.0027

Title: Result of Reactor Physics Safety Analysis for Advanced Test Reactor Cycle 152B-1

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Table A7. Summary of ATR Shim Positions for ATR Cycle 152B-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 1 1	56.6	1 1 1 1 1 1	56.6	1 1 1 0 1 1	0.0	1 1 1 0 1 1
NE	56.6	1 1 1 1 1 1	153.9	1 1 1 1 1 1	0.0	1 1 1 0 1 1	56.6	1 1 1 0 1 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	56.6	1 1 1 1 1 1	0.0	1 1 1 1 1 1	153.9	1 1 1 0 1 1	56.6	1 1 1 0 1 1
SE	0.0	1 1 1 1 1 1	56.6	1 1 1 1 1 1	56.6	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**	**C**	**SW**	**SE**	**$K_{effective}$**
NW	104	26.8042	14.4013	23.7651	23.7614	15.2680	0.9908
NE	104	14.6918	26.3793	23.9225	15.9831	23.0223	0.9900
C	104	15.4666	15.8324	31.4540	21.3246	19.9223	1.0118
SW	104	13.1174	8.7376	21.9967	41.3663	18.7821	1.0150
SE	104	8.9932	13.2103	22.1635	19.8809	39.7521	1.0130

Title: Result of Reactor Physics Safety Analysis for Advanced Test Reactor Cycle 152B-1

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Table A9. Summary of Fuel Element Powers for ATR Cycle 152B-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	104.0	2.7	2.5	2.1	1.5	1.2	1.2	1.7	2.4	2.6	3.0
0	104.0	2.6	2.4	2.1	1.4	1.1	1.1	1.6	2.3	2.6	2.9
3	104.0	2.6	2.3	2.2	1.6	1.4	1.4	1.8	2.4	2.4	2.7
10	104.0	2.5	2.3	2.1	1.6	1.3	1.4	1.8	2.4	2.4	2.7
17	104.0	2.6	2.5	2.2	1.6	1.4	1.4	1.8	2.4	2.6	2.7
24	104.0	2.5	2.4	2.1	1.5	1.3	1.4	1.7	2.4	2.5	2.7
31	104.0	2.5	2.4	2.1	1.5	1.3	1.3	1.7	2.3	2.6	2.7
38	104.0	2.8	2.6	2.1	1.5	1.3	1.3	1.7	2.4	2.7	3.0
45	104.0	2.7	2.5	2.1	1.5	1.3	1.4	1.7	2.3	2.6	2.9
52	104.0	2.6	2.4	2.1	1.6	1.4	1.5	1.8	2.4	2.5	2.8
53	104.0	2.6	2.4	2.1	1.6	1.4	1.5	1.8	2.3	2.5	2.8

Time At Power (Days)	Total Core Power (MW)	Power (MW) For Fuel Element In Core Positions 11-20									
		11	12	13	14	15	16	17	18	19	20
0	104.0	3.3	3.4	3.3	2.8	2.3	2.3	2.8	3.4	3.5	3.4
0	104.0	3.2	3.3	3.3	2.8	2.3	2.3	2.8	3.3	3.4	3.3
3	104.0	3.0	3.1	3.2	2.8	2.6	2.6	2.8	3.2	3.2	3.1
10	104.0	3.0	3.2	3.2	2.9	2.6	2.6	2.9	3.3	3.3	3.1
17	104.0	3.1	3.2	3.3	2.9	2.6	2.6	2.8	3.3	3.3	3.2
24	104.0	3.2	3.2	3.3	2.9	2.6	2.6	2.9	3.3	3.3	3.3
31	104.0	3.1	3.2	3.2	2.8	2.5	2.5	2.8	3.3	3.3	3.2
38	104.0	3.1	3.1	3.2	2.8	2.5	2.5	2.8	3.2	3.2	3.2
45	104.0	3.0	3.1	3.2	2.9	2.6	2.6	2.9	3.2	3.2	3.1
52	104.0	3.0	3.1	3.2	3.0	2.7	2.7	2.9	3.2	3.2	3.1
53	104.0	3.0	3.1	3.2	3.0	2.7	2.7	3.0	3.2	3.2	3.1

Title: Result of Reactor Physics Safety Analysis for Advanced Test Reactor Cycle 152B-1

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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	104.0	3.5	3.8	3.6	3.0	2.4	2.4	2.8	3.4	3.6	3.3
0	104.0	3.4	3.6	3.4	2.8	2.3	2.3	2.7	3.3	3.5	3.2
3	104.0	3.1	3.3	3.2	2.8	2.5	2.5	2.7	3.2	3.2	3.0
10	104.0	3.1	3.2	3.2	2.8	2.5	2.5	2.7	3.1	3.1	2.9
17	104.0	3.0	3.2	3.2	2.8	2.6	2.6	2.7	3.1	3.1	2.9
24	104.0	3.0	3.2	3.2	2.8	2.5	2.5	2.7	3.1	3.1	2.8
31	104.0	3.0	3.3	3.3	2.9	2.6	2.6	2.7	3.2	3.2	2.8
38	104.0	3.0	3.4	3.2	2.8	2.4	2.4	2.6	3.1	3.2	2.8
45	104.0	3.2	3.5	3.2	2.8	2.4	2.4	2.6	3.1	3.3	3.0
52	104.0	3.2	3.4	3.2	2.8	2.4	2.4	2.6	3.1	3.3	3.0
53	104.0	3.2	3.4	3.2	2.8	2.4	2.4	2.6	3.1	3.3	3.0

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	104.0	2.9	2.8	2.3	1.6	1.3	1.2	1.5	2.0	2.6	2.7
0	104.0	2.9	2.9	2.6	2.0	1.8	1.7	1.9	2.3	2.7	2.7
3	104.0	3.1	3.0	2.6	2.0	1.8	1.8	1.9	2.3	2.9	2.9
10	104.0	3.0	3.0	2.6	2.1	1.9	1.9	2.0	2.3	2.9	2.8
17	104.0	2.9	2.9	2.5	2.0	1.8	1.8	1.9	2.3	2.8	2.8
24	104.0	2.9	2.9	2.5	2.0	1.9	1.8	1.9	2.3	2.8	2.7
31	104.0	2.9	2.9	2.5	2.1	1.9	1.9	2.0	2.3	2.8	2.7
38	104.0	2.8	2.9	2.5	2.0	1.9	1.9	2.0	2.3	2.8	2.7
45	104.0	2.8	2.9	2.5	2.0	1.9	1.9	1.9	2.2	2.7	2.7
52	104.0	2.7	2.8	2.4	2.1	1.9	1.9	2.0	2.2	2.7	2.6
53	104.0	2.7	2.8	2.4	2.1	1.9	1.9	2.0	2.2	2.7	2.6

Title: Result of Reactor Physics Safety Analysis for Advanced Test Reactor Cycle 152B-1

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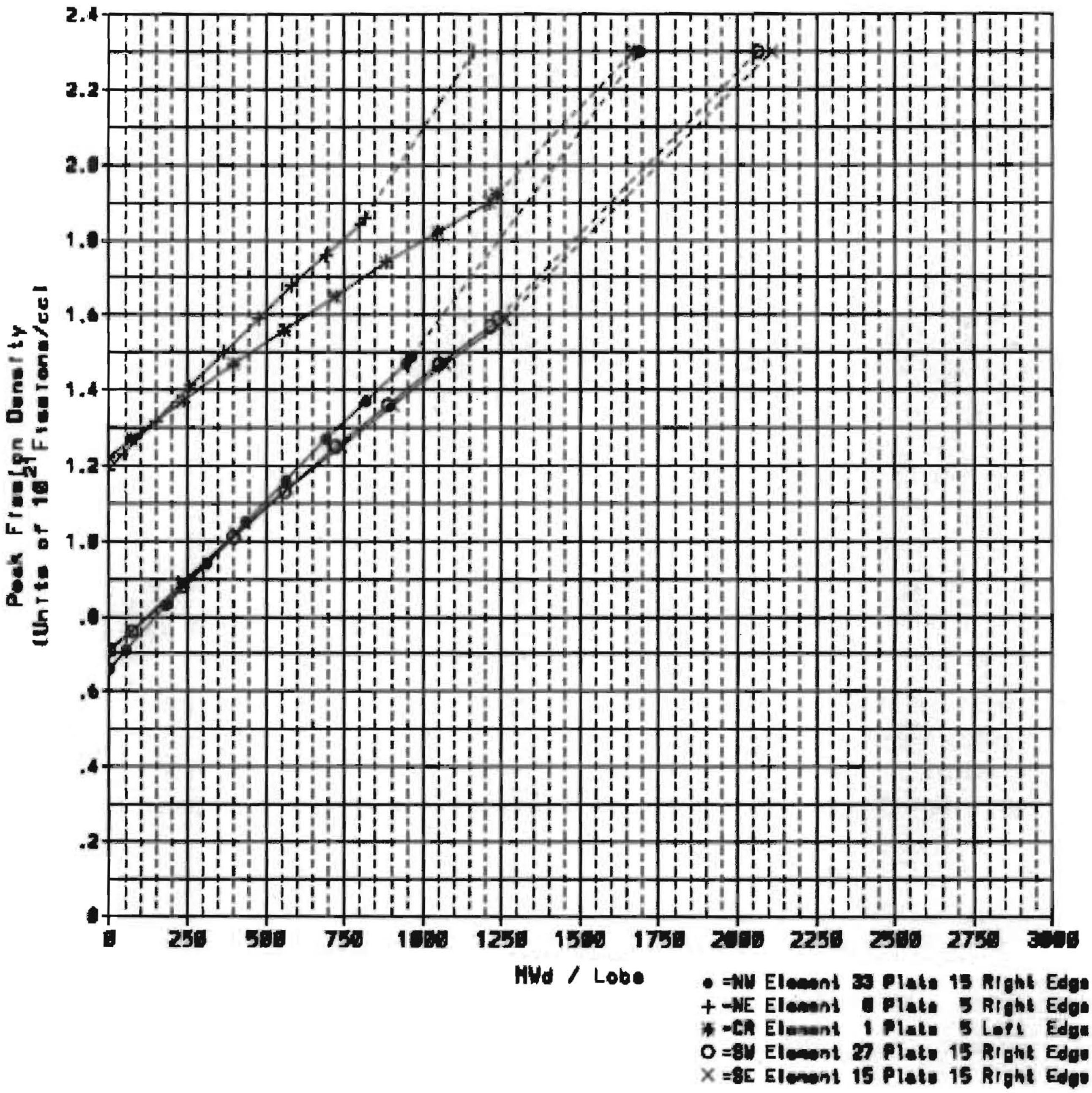
Figure A1. Fission Density for the Limiting Element in each Lobe for ATR Cycle 152B-1



Title: Result of Reactor Physics Safety Analysis for Advanced Test Reactor Cycle 152B-1

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Figure A2. Estimated total core excess reactivity during ATR Cycle 152B-1