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ECAR-2220Results Of Reactor Physics Safety Analysis For Advanced Test Reactor Cycle 154A-1

March 2022

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Changing the World's Energy Future

Idaho National Laboratory

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Title: Results of Reactor Physics Safety Analysis for Advanced Test Reactor Cycle 154A-1

ECAR No.: 2220 Rev. No.: 0 Project No.: N/A Date: 4/9/2013

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 154A-1 reported in this Engineering Calculations and Analysis Report (ECAR) were obtained using the PDQ 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 154A-1. The physics analysis contained herein was performed using a total core power of 103 MW with a fuel loading for 56 days. The results of the calculation show that none of the SAR/TSR limits will be violated during Cycle 154A-1 when operating with two primary coolant pumps (2-PCP operation).

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APPENDIXES

Title: Results of Reactor Physics Safety Analysis for Advanced Test Reactor Cycle 154A-1

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PROJECT ROLES AND RESPONSIBILITIES

Project Role	Name (Typed)	Organization	Pages covered (if applicable)
Performer	P. A. Roth	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.*

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 154A-1 reported in this Engineering Calculations and Analysis Report (ECAR) were obtained using the PDQ X-Y model of the ATR core. Reference 1 identifies a SAR-153 commitment to use the PDQ 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, Reference 11.

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-15-12, Rev.0, Advanced Test Reactor Cycle 154A Preliminary Experiment Requirements Letter, Revision 0, January 15, 2013

4. R. A. Jordan letter to ATR Cycle Reference Document 15, RAJ-6-13, Requested Lobe Powers for Advanced Test Reactor (ATR) Cycle 154A-1 Startup, April 2, 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. P. A. Roth, 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. GDE-175, ATR Core Physics Calculations Using PDQWS, Revision 0, October 8, 2012.

12. C. B. Davis, Evaluation of Variations in the ATR Axial Power Distribution on Core Safety Margins, ECAR-2179, March 5, 2013.

Appendix A

Results of Reactor Physics Safety Analysis for Advanced Test Reactor (ATR) Cycle 154A

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 PDQ X-Y model of the ATR core. Reference 1 identifies a SAR-153 commitment to use the 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 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.

PDQ analysis of Cycle 154A-1 assumes operation for 56 days (Reference 3) using a nominal lobe power (MW) division of 20-16-24-20-23 (NW-NE-C-SW-SE) for a total reactor power of 103 MW. Computation of EPP values assumes maximum lobe powers (MW) of 23-19-29-23-26 (NW-NE-C-SW-SE) for normalization (References 3 and 4). Loop experiments (Reference 3) included in the PDQ model used for this calculation are shown in Table A1, along with lobe nominal, minimum, and maximum powers (Reference 4).

Data

The Cycle 154A-1 fuel charge consists of the following fuel elements:

14 New 7F elements	26 recycle 7F elements
0 New NB elements	0 recycle NB elements
0 New YA elements	0 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, NE, 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 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 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 narrow coolant channel restrictions.

Analysis and Calculations

The calculation was performed using the PDQ computer code on the castalia workstation. PDQ 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 PDQ 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 154A-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 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 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) 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	0	210
NE	417	443	F-9	5	100	0	204
C	417	443	F-11	5	100	3, 24	228
SW	417	443	F-22	5	100	0	230
SE	412[a]	438[a]	F-12	1	100	0	251

a EPP limit reduced by 1.1% - see 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	417	443	F-32	5	100	0	210
NE	417	443	F-10	5	100	3	226
SW	417	443	F-22	5	100	0	230
SE	412[a]	438[a]	F-12	1	100	0	251

a EPP limit reduced by 1.1% - see reference 12

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	417	445	F-33	19	100	0	180
NE	417	445	F-8	19	100	0	171
C	417	445	F-11	19	100	38	139
SW	417	445	F-23	19	100	0	174
SE	412[a]	440[a]	F-13	19	100	0	230

a EPP limit reduced by 1.1% - see reference 12

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 154A-1 elements at each time step are given in Table 4.

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Table 4. Limiting EPP at Each Time Step

Plate Type	EPP Limit 2 PCP	Cycle 154A-1 Most Limiting EPP	Position	Plate	Restricted to (%) of limit	Days[b]
19	412[a]	230	F-13	19	100	0
Inner	412[a]	251	F-12	1	100	0
19	412[a]	210	F-13	19	100	3
Inner	417	228	F-11	5	100	3
19	412[a]	205	F-13	19	100	10
Inner	417	227	F-11	5	100	10
19	412[a]	202	F-13	19	100	17
Inner	417	224	F-11	5	100	17
19	412[a]	197	F-13	19	100	24
Inner	417	228	F-11	5	100	24
19	412[a]	193	F-13	19	100	31
Inner	417	226	F-11	5	100	31
19	412[a]	186	F-13	19	100	38
Inner	417	223	F-11	5	100	38
19	412[a]	180	F-13	19	100	45
Inner	417	216	F-11	5	100	45
19	412[a]	173	F-13	19	100	52
Inner	412[a]	209	F-12	5	100	52
19	412[a]	168	F-13	19	100	56
Inner	412[a]	205	F-12	5	100	56

a EPP limit reduced by 1.1% - see reference 12

b 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, NE, SW, and SE lobes. 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.

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

Lobe/Plate	Effective Plate Power Limit		Cycle 154A-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	406	431	160	F-34	15	45,52,56	100
NW/Plate 19	358	357	146	F-34	19	31	100
NE/Inner Plates	406	431	127	F-7	15	31	100
NE/Plate 19	358	357	107	F-7	19	24,31	100
SW/Inner Plates	406	431	150	F-24	15	17	100
SW/Plate 19	358	357	122	F-27	19	10,17	100
SE/Inner Plates	401[a]	426[a]	177	F-14	15	56	100
SE/Plate 19	354[a]	353[a]	161	F-14	19	3	100

a EPP limit reduced by 1.1% - see reference 12

The elements in several positions of the fuel loading for this cycle reach a fission density greater than $1.5\text{x}10^{21}$ 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 $1.5\ \text{x}10^{21}$ 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	40
3	40
10	1, 40
17	1, 40
24	1, 11, 15, 16, 26, 30, 40
31	1, 7, 9, 10, 11, 15, 16, 20, 21, 26, 30, 31, 40
38	1, 2, 3, 7, 8, 9, 10, 11, 15, 16, 20, 21, 24, 25, 26, 27, 30, 31, 40
45	1, 2, 3, 4, 7, 8, 9, 10, 11, 15, 16, 17, 20, 21, 23, 24, 25, 26, 27, 28, 30, 31, 40
52	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 15, 16, 17, 20, 21, 23, 24, 25, 26, 27, 28, 30, 31, 40
56	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 15, 16, 17, 20, 21, 23, 24, 25, 26, 27, 28, 30, 31, 40

Once an element exceeds 1.5 x 10^{21} fission density, its effective point power must not exceed the appropriate limit for its position as defined in Reference 9. 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 154A-1 Most Limiting Effective Point Power By Lobe				
	2 PCP	3 PCP	Position	Plate	Restricted to (%) of limit	Days	EPtP
NW	446	465	N/A	N/A	N/A	N/A	N/A
NE	446	465	F-9	5	100	31	221
C	446	465	F-11	5	100	24	277
SW	446	465	F-23	15	100	45	200
SE	430[a]	448[a]	F-16	15	100	24	191

a EPP limit reduced by 1.1% - see reference 12

N/A = not applicable – no positions in NW are >1.5 x 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 154A-1 Most Limiting Effective Point Power By Lobe				
	2 PCP	3 PCP	Position	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	38	169
C	411	428	F-11	19	100	38	162
SW	411	428	F-23	19	100	45	169
SE	406[a]	423[a]	F-16	19	100	24	154

a EPP limit reduced by 1.1% - see reference 12

N/A = not applicable – no positions in NW are $>1.5 \times 10^{21}$

The worst-case lobe powers equivalent to the TSR-186 3.6.1a, Table 3.6.1-1 EPP limits are shown in Table 9. Worst-cases lobe powers are calculated by simulating a lobe power unbalance accident using maximum shim unbalances in the PDQ model and the results are subsequently scaled to the limiting EPP.

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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	30.57	All, inner plates	226	F-35	15	1.00	659/1.45 = 454	61.4
			All, plate 19	222	F-35	19	1.00	659/1.45 = 454	62.5
			< 2σ, inner plates	226	F-35	15	1.00	641/1.45 = 442	59.7
			< 2σ, plate 19	222	F-35	19	1.00	490/1.37 = 357	49.1*
NE	19.0	30.82	All, inner plates	216	F-9	5	1.00	659/1.45 = 454	64.7
			All, plate 19	197	F-7	19	1.00	659/1.45 = 454	71.0
			< 2σ, inner plates	209	F-7	15	1.00	641/1.45 = 442	65.1
			< 2σ, plate 19	197	F-7	19	1.00	490/1.37 = 357	55.8*
CR	29.0	30.32	All, inner plates	218	F-11	5	1.00	659/1.45 = 454	63.1*
			All, plate 19	131	F-11	19	1.00	659/1.45 = 454	105.0
SW	23.0	38.97	All, inner plates	264	F-25	15	1.00	659/1.45 = 454	67.0
			All, plate 19	245	F-25	19	1.00	659/1.45 = 454	72.2
			< 2σ, inner plates	264	F-25	15	1.00	641/1.45 = 442	65.2
			< 2σ, plate 19	245	F-25	19	1.00	490/1.37 = 357	56.7*
SE	26.0	41.72	All, inner plates	308	F-14	15	1.00	659/1.45 = 454	61.4
			All, plate 19	291	F-14	19	1.00	659/1.45 = 454	65.0
			< 2σ, inner plates	308	F-14	15	1.00	641/1.45 = 442	59.8
			< 2σ, plate 19	291	F-14	19	1.00	490/1.37 = 357	51.1*

*indicates the minimum value for that lobe

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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 154A-1 is 4.103 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 2.84 in position F-13 for the time step 0.

The preliminary startup power division normalized to a total core power of 250 MW is: 39.2-40.1-60.4-52.6-57.7 (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 X 10^{21} fissions/cc)	
Lobe	**MWd**	**Time in Cycle[b] (Days)**	**MWd**	**Time in Cycle[c] (Days)**
NW	1220	61.0	2236	97.2
NE	1128	70.5	1258	66.2
C	---	---	1527	52.6
SW	1444	72.2	1952	84.8
SE	1582	68.7	1998	76.8

a. The reactivity estimates were obtained using the XSPRJ method.
b. The Time in Cycle is based on the nominal power division of 20-16-24-20-23 (NW-NE-C-SW-SE).
c. The Time in Cycle is based on the maximum power division of 23-19-29-23-26 (NW-NE-C-SW-SE).

The results above show sufficient reactivity in all lobes to sustain the requested lobe power for the cycle length of 56 days. The results also show that the fission density limits should not be exceeded for a cycle length of 56 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 29 MW. To achieve the fission density limit during a 56 day cycle, a C lobe average power of approximately 27.2 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.

The following element in the fuel loading for Cycle 154A-1 is expected to have no further recycle potential after the nominal operation of Cycle 154A-1:

Core Position	Element ID
F-40	XA233T

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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ECAR No.: 2220 Rev. No.: 0 Project No.: N/A Date: 4/9/2013

Table A1. Experimental Designations and Nominal Power Division for ATR Cycle 154A-1[3,4]

Lobe	Power	Loop Experiments	
NW	20^{+3}_{-3}	2E/NW-162	(ATRC-2E-NW-162-00)
N	-	1D/N-106	(ATRC-1D-N-106-00)
NE	16^{+3}_{-3}	AGR 3/4	(SBG-05-11)
W	-	1C/W-75	(ATRC-1C-W-75-00)
C	24^{+5}_{-5}	EPRI-3	(DCJ-04-12)
E	-	7-pin SIHA	(DWG443208)
SW	20^{+3}_{-3}	2D/SW-188	(ATRC-2D-SW-188-01)
S	-	SPICE 9	(ATRC-S-M-101-01)
SE	23^{+3}_{-3}	2B/SE-192	(ATRC-2B-SE-192-03)

Title: Result of Reactor Physics Safety Analysis for Advanced Test Reactor Cycle 154A-1

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Table A2. Summary of Fuel Load for Cycle 154A-1

Core Pos.	Serial No.	Content ^{235}U	^{10}B	Total MWD	Irradiation History Cycle	Pos.	Cycle	Pos.
1	XA693T	805	0.087	1898	142A-1	8	143B-1	5
2	XA955T	860	0.124	1180	151B-1	18		
3	XA965T	860	0.124	1182	151B-1	23		
4	XA704T	861	0.128	1193	142A-1	28		
5	XA812T	861	0.126	1191	144B-1	18		
6	XA822T	861	0.125	1191	144B-1	23		
7	XA016U	861	0.162	1289	151A-1	12		
8	XA646T	862	0.130	1197	142B-1	33		
9	XA017U	863	0.129	1289	151A-1	13		
10	XA740T	860	0.129	1435	143B-1	14		
11	XA832T	855	0.123	1408	145A-1	17		
12	XA032U	1075	0.660					
13	XA033U	1075	0.660					
14	XA034U	1075	0.660					
15	XA237T	847	0.112	1224	148B-1	23		
16	XA742T	851	0.119	1435	143B-1	17		
17	XA921T	940	0.247	883	149A-1	27		
18	XA035U	1075	0.660					
19	XA036U	1075	0.660					
20	XA851T	859	0.123	1185	148B-1	18		
21	XA866T	854	0.127	1370	146B-1	3	149A-1	7
22	XA030U	1075	0.660					
23	XA941T	910	0.231	966	150B-1	12		
24	XA953T	896	0.174	1180	151B-1	14		
25	XA225T	885	0.175	927	148B-1	2		
26	XA226T	836	0.107	1360	148B-1	3	150A-1	19
27	XA828T	886	0.160	1313	146A-1	16		
28	XA963T	902	0.208	965	150B-1	29		
29	XA031U	1075	0.660					
30	XA678T	854	0.130	1495	140B-1	3	142A-1	7
31	XA811T	860	0.130	1408	145B-1	27		
32	XA018U	1075	0.660					
33	XA021U	1075	0.660					
34	XA022U	1075	0.660					
35	XA025U	1075	0.660					
36	XA961T	927	0.223	965	150B-1	27		
37	XA027U	1075	0.660					
38	XA028U	1075	0.660					
39	XA029U	1075	0.660					
40	XA233T	817	0.096	1446	148B-1	22	150A-1	6

Title: Result of Reactor Physics Safety Analysis for Advanced Test Reactor Cycle 154A-1

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Table A3. Plate Restrictions for Fuel Loaded in Cycle 154A-1[9,10,12]

Core Pos.	Serial No.	Restriction	Restricted Plates (of those represented in the PDQ model)
1	XA693T		
2	XA955T		
3	XA965T		
4	XA704T		
5	XA812T		
6	XA822T		
7	XA016U		
8	XA646T		
9	XA017U		
10	XA740T		
11	XA832T		
12	XA032U		
13	XA033U		
14	XA034U		
15	XA237T		
16	XA742T		
17	XA921T		
18	XA035U		
19	XA036U		
20	XA851T		
21	XA866T		
22	XA030U		
23	XA941T		
24	XA953T		
25	XA225T		
26	XA226T		
27	XA828T		
28	XA963T		
29	XA031U		
30	XA678T		
31	XA811T		
32	XA018U		
33	XA021U		
34	XA022U		
35	XA025U		
36	XA961T		
37	XA027U		
38	XA028U		
39	XA029U		
40	XA233T		

Table A4. Capsule Facility Loading Used in ATR Cycle 154A-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	EPRI –ZG-B	GWW-10-11
A-15	LSFR	
A-16	LSFR	
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	LUNA	SBG-06-12
B-9	Aluminum Filler	
B-10	Aluminum Filler	
B-11	Aluminum Filler	
B-12	AGR-2	SBG-07-12, Rev.1

Title: Result of Reactor Physics Safety Analysis for Advanced Test Reactor Cycle 154A-1

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Table A4. Continued

Facility	Description	Reference
H-1	LSA Cobalt	CSR-06-12
H-2	LSA Cobalt	CSR-06-12
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	LSA Cobalt	CSR-06-12
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	

Table A5. Summary of ATR Shim Positions for ATR Cycle 154A-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	46.5	1 2 3 4 5 6	46.5	1 2 3 4 5 6	46.5	1 2 3 5 6	46.5	1 2 3 5 6
0	69.7	1 2 3 4 5 6	40.1	1 2 3 4 5 6	40.1	1 2 3 5 6	51.2	1 2 3 5 6
3	85.4		69.7	1 2 3 4 5 6	69.7	1 2 3 5 6	85.4	1 2 3 5 6
10	89.8		69.7	1 2 3 4 5 6	75.2	1 2 3 5 6	85.4	1 2 3 5
17	95.2		75.2	1 2 3 4 5 6	79.3	1 2 3 5 6	85.4	1 2 3 5
24	100.1		79.3	1 2 3 4 5 6	79.3	1 2 3 5 6	85.4	1 2 3
31	111.7		85.4	1 2 3 4 5 6	85.4	1 2 3 5	85.4	1
38	116.4		85.4	1 2 3 4 5	85.4	1 2 3	89.8	
45	119.6		85.4	1 2 3 4	85.4	1 2	95.2	
52	124.4		85.4	1 2 3	85.4		100.1	
56	134.2		85.4	1	95.2		111.7	

Table A6. Summary of ATR Core Power and Calculated $K_{effective}$ for ATR Cycle 154A-1

Time At Power (Days)	Total Core Power (MW)	Lobe Powers (MW) NW	NE	C	SW	SE	$K_{effective}$
0	103	16.1	16.5	24.9	21.7	23.8	0.9831
0	103	19.2	15.6	24.5	20.2	23.5	0.9863
3	103	19.1	16.1	22.8	20.7	24.4	0.9910
10	103	19.0	15.6	22.4	21.2	24.8	0.9929
17	103	19.6	15.8	22.0	21.4	24.2	0.9921
24	103	19.8	16.0	21.8	20.7	24.7	0.9921
31	103	20.1	15.6	21.7	21.3	24.2	0.9974
38	103	19.9	15.6	21.8	21.2	24.5	0.9995
45	103	20.0	15.8	21.7	20.8	24.7	0.9985
52	103	19.9	15.6	22.0	20.8	24.6	0.9987
56	103	19.5	15.6	21.9	21.0	24.9	1.0029

Table A7. Summary of ATR Shim Positions for ATR Cycle 154A-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	46.5	1 1 1 1 1 1	46.5	1 1 1 0 1 1	0.0	1 1 1 0 1 1
NE	46.5	1 1 1 1 1 1	153.9	1 1 1 1 1 1	0.0	1 1 1 0 1 1	46.5	1 1 1 0 1 1
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	46.5	1 1 1 1 1 1	0.0	1 1 1 1 1 1	153.9	1 1 1 0 1 1	46.5	1 1 1 0 1 1
SE	0.0	1 1 1 1 1 1	46.5	1 1 1 1 1 1	46.5	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	103	30.5782	14.9238	22.9557	19.2923	15.2500	0.996738
NE	103	14.4487	30.8284	22.8900	13.8189	21.0140	0.999252
C	103	16.1196	16.7541	28.0575	20.1883	21.8806	1.035208
SW	103	13.4933	9.7762	21.9328	38.9777	18.8201	1.015177
SE	103	9.1450	13.6308	21.6903	16.8045	41.7294	1.020719

Title: Result of Reactor Physics Safety Analysis for Advanced Test Reactor Cycle 154A-1

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Table A9. Summary of Fuel Element Powers for ATR Cycle 154A-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	103	2.7	2.6	2.3	1.6	1.3	1.3	1.8	2.7	3.0	3.2
0	103.0	2.7	2.5	2.2	1.5	1.2	1.2	1.6	2.5	2.9	3.1
3	103.0	2.5	2.4	2.2	1.7	1.4	1.4	1.8	2.5	2.6	2.8
10	103.0	2.4	2.3	2.2	1.7	1.4	1.4	1.7	2.4	2.6	2.7
17	103.0	2.4	2.3	2.2	1.7	1.5	1.5	1.8	2.4	2.5	2.7
24	103.0	2.3	2.2	2.2	1.7	1.5	1.5	1.8	2.4	2.5	2.7
31	103.0	2.2	2.2	2.1	1.7	1.5	1.5	1.8	2.4	2.4	2.6
38	103.0	2.2	2.2	2.1	1.7	1.5	1.5	1.8	2.4	2.5	2.6
45	103.0	2.2	2.3	2.1	1.7	1.5	1.5	1.8	2.4	2.6	2.6
52	103.0	2.3	2.3	2.1	1.7	1.4	1.5	1.7	2.3	2.6	2.6
56	103.0	2.4	2.4	2.1	1.6	1.4	1.4	1.7	2.3	2.6	2.8

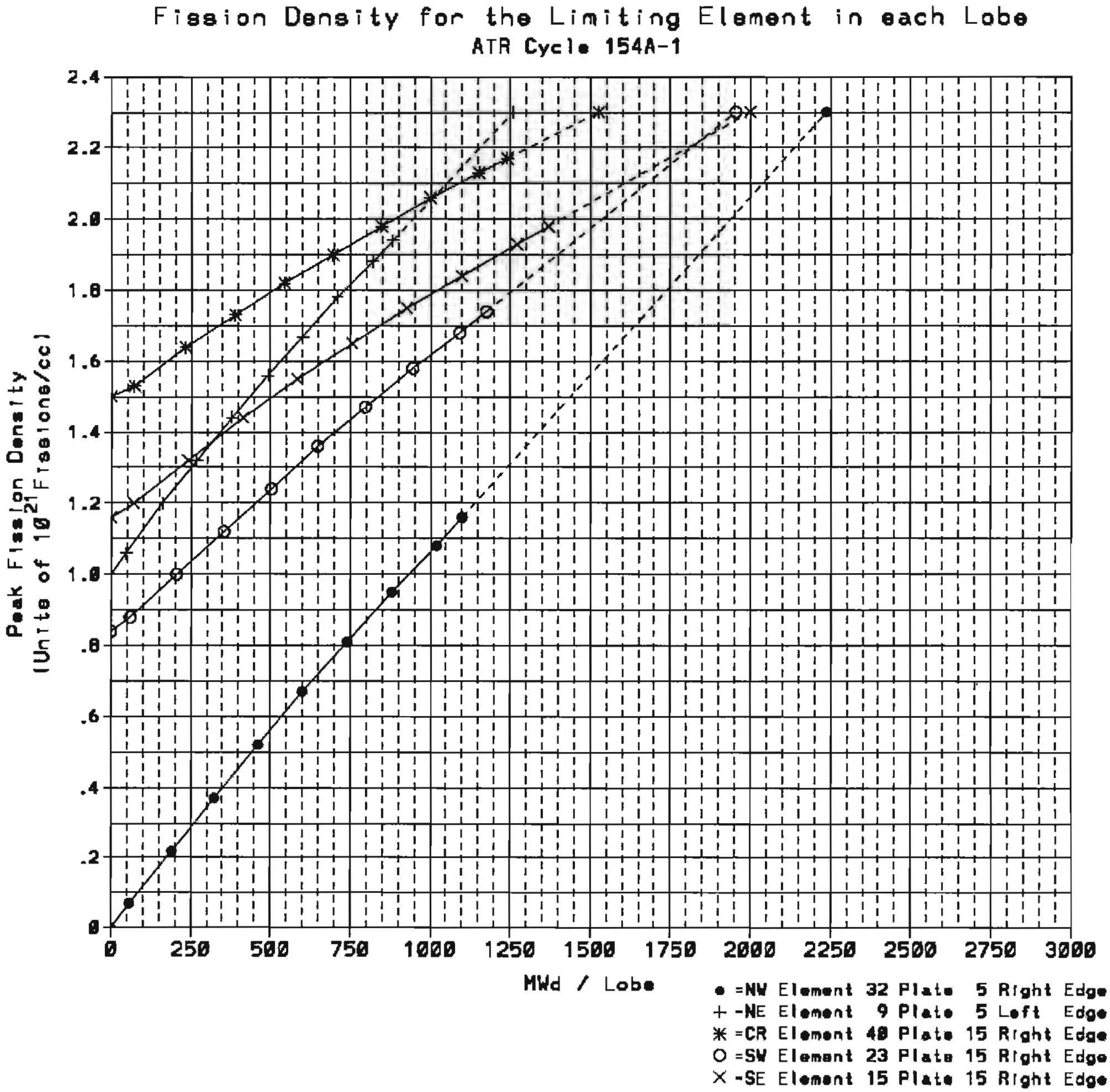
Time At Power (Days)	Total Core Power (MW)	Power (MW) For Fuel Element In Core Positions 11-20									
		11	12	13	14	15	16	17	18	19	20
0	103.0	3.4	3.8	3.5	2.7	2.0	2.1	2.6	3.4	3.7	3.4
0	103.0	3.3	3.7	3.4	2.7	2.1	2.1	2.6	3.4	3.6	3.3
3	103.0	3.0	3.3	3.4	2.9	2.6	2.6	2.9	3.3	3.3	2.9
10	103.0	3.0	3.5	3.4	3.0	2.6	2.6	2.9	3.4	3.4	2.9
17	103.0	2.9	3.4	3.4	2.9	2.5	2.6	2.8	3.3	3.3	2.9
24	103.0	2.9	3.5	3.4	2.9	2.5	2.6	2.8	3.4	3.5	2.9
31	103.0	3.0	3.6	3.4	2.9	2.4	2.4	2.7	3.3	3.5	3.0
38	103.0	3.1	3.6	3.4	2.9	2.5	2.5	2.8	3.4	3.5	3.1
45	103.0	3.0	3.6	3.4	3.0	2.5	2.5	2.8	3.4	3.5	3.0
52	103.0	3.0	3.5	3.4	3.0	2.5	2.5	2.8	3.4	3.5	3.0
56	103.0	3.0	3.5	3.4	3.1	2.6	2.6	2.9	3.4	3.4	3.0

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	103.0	3.4	3.6	3.1	2.4	2.0	1.9	2.3	2.9	3.4	3.1
0	103.0	3.3	3.4	2.9	2.2	1.7	1.7	2.1	2.8	3.3	3.1
3	103.0	2.9	3.1	2.9	2.4	2.1	2.0	2.3	2.8	3.0	2.8
10	103.0	2.9	3.1	3.0	2.5	2.2	2.2	2.4	2.8	3.0	2.8
17	103.0	2.8	3.1	3.0	2.5	2.3	2.2	2.5	2.8	3.0	2.7
24	103.0	2.8	3.0	2.9	2.4	2.2	2.1	2.4	2.7	2.9	2.7
31	103.0	2.8	3.2	2.9	2.5	2.3	2.2	2.4	2.8	3.0	2.7
38	103.0	2.8	3.3	2.9	2.4	2.2	2.1	2.4	2.7	3.1	2.7
45	103.0	2.8	3.3	2.9	2.4	2.2	2.1	2.3	2.7	3.1	2.7
52	103.0	3.0	3.3	2.8	2.4	2.1	2.1	2.3	2.7	3.2	2.9
56	103.0	2.9	3.3	2.9	2.4	2.2	2.1	2.3	2.7	3.1	2.8

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	103.0	2.9	2.8	2.4	1.7	1.3	1.2	1.7	2.2	2.7	2.7
0	103.0	2.9	3.0	2.8	2.2	1.9	1.8	2.1	2.6	2.9	2.7
3	103.0	3.0	3.1	2.7	2.1	1.9	1.8	2.1	2.5	3.0	2.8
10	103.0	2.9	3.0	2.6	2.1	1.9	1.9	2.1	2.4	2.9	2.7
17	103.0	2.9	3.0	2.7	2.2	2.1	2.0	2.2	2.5	2.9	2.7
24	103.0	2.8	3.0	2.7	2.3	2.1	2.0	2.2	2.5	2.9	2.7
31	103.0	2.8	3.0	2.7	2.4	2.2	2.1	2.3	2.5	2.8	2.6
38	103.0	2.7	2.9	2.7	2.4	2.2	2.1	2.3	2.5	2.8	2.5
45	103.0	2.7	2.9	2.7	2.4	2.3	2.1	2.3	2.5	2.8	2.5
52	103.0	2.7	2.9	2.7	2.4	2.3	2.1	2.3	2.5	2.8	2.5
56	103.0	2.6	2.8	2.6	2.4	2.2	2.1	2.3	2.4	2.7	2.5

Figure A1. Fission Density for the Limiting Element in each Lobe for ATR Cycle 154A-1



Title: Result of Reactor Physics Safety Analysis for Advanced Test Reactor Cycle 154A-1

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Figure A2. Estimated total core excess reactivity during ATR Cycle 154A-1