INL/CON-23-75296-Revision-0

Transport Modeling of As-Run ATR Cycles for U-10Mo Fuel Qualification Experiment

November 2023

Paul E Gilbreath

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Idaho National Laboratory

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November 14, 2023

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MAINTAINING the MOMENTUM

Idaho National Laboratory

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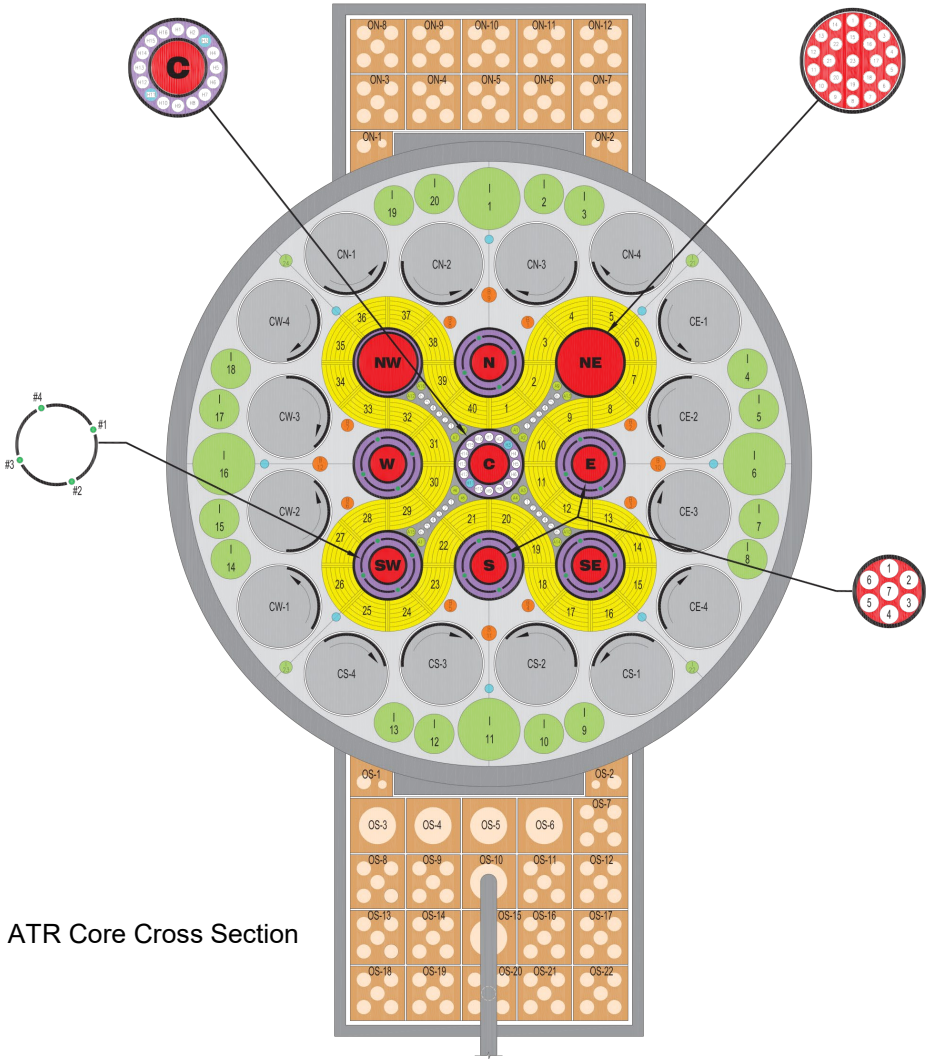


ATR Core Cross Section

Outline:

- Background
- Experiment Description
- Model Description
- As-Run Methods
- Results
- Validation of Results
- Acknowledgements

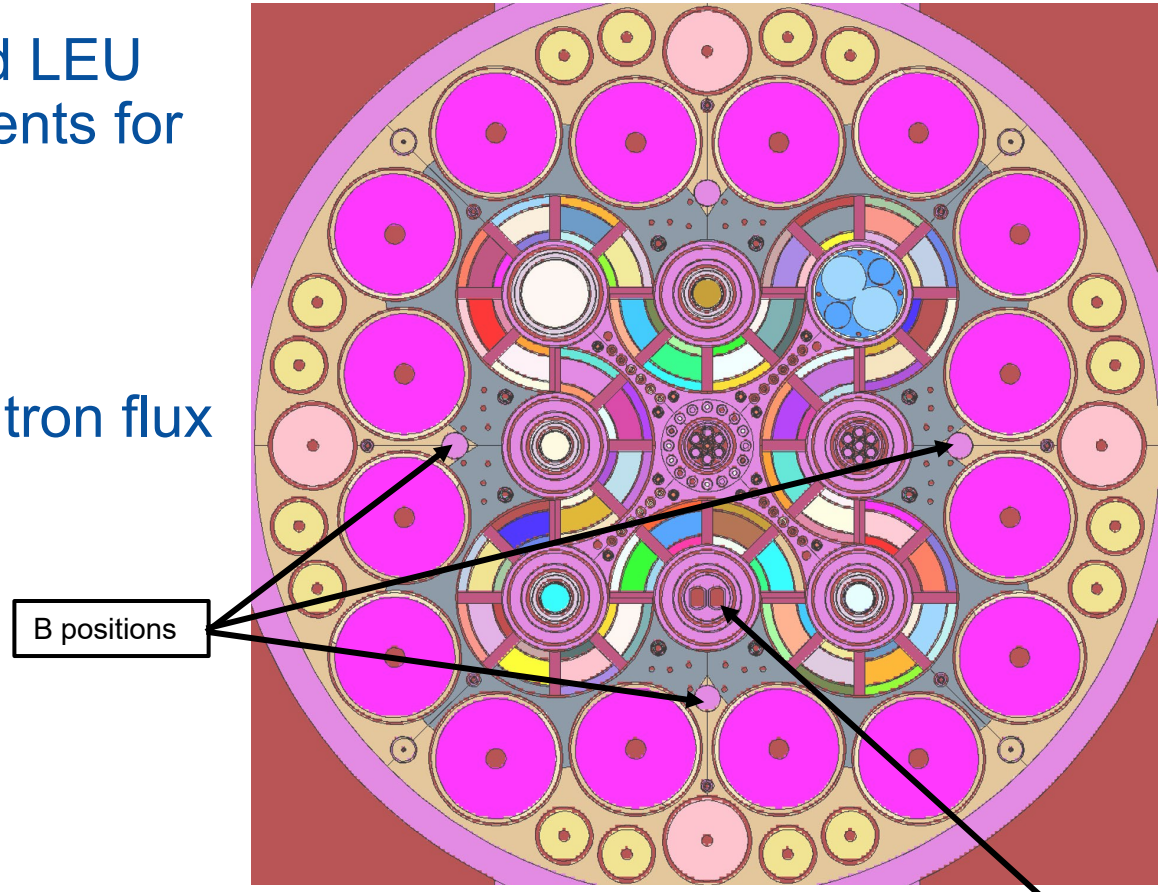
Background

- The U.S. Department of Energy (DOE) Office of Materials Management and Minimization needs to convert the five U.S. High Performance Research Reactors (HPRR) from highly enriched uranium to low enriched uranium (LEU).
- Reactors regulated by the Nuclear Regulatory Commission (NRC):
  - Massachusetts Institute of Technology Reactor (MITR)
  - University of Missouri's Research Reactor (MURR)
  - National Bureau of Standards Reactor (NBSR)
- Reactors regulated by DOE:
  - High Flux Isotope Reactor
  - Advanced Test Reactor (ATR)

- The first mini-plate experiment (MP-1) focuses on the NRC reactors

MP-1 Experiment Description

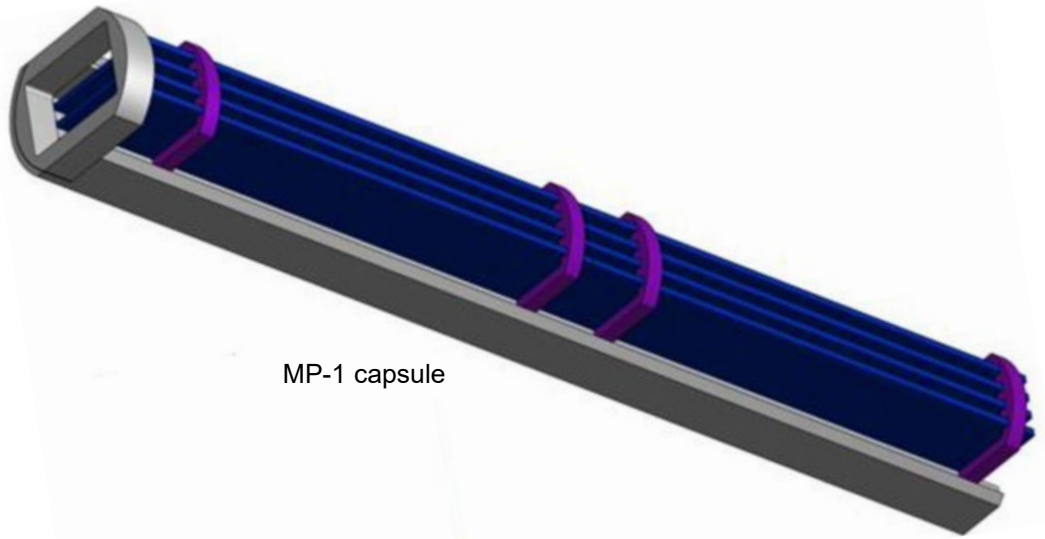
- Goal to demonstrate commercially fabricated LEU fuel meets irradiation performance requirements for NRC reactors
- ATR is the chosen reactor to support fuel qualification:
  - Many experiment positions with high neutron flux
  - Can support many irradiation conditions
- MP-1 experiment positions in the ATR:
  - B-10, B-11, B-12 positions
  - South Flux Trap
- ATR cycles 164A, 164B, and 166A



ATR MCNP Full Core Model

MP-1 Experiment Description

- Single test train in “B” positions and two test trains in the South Flux Trap
  - Test train contains four capsules
  - Capsule contains two rows of four plates
- Hafnium rings suppress corner peaking
  (except ATR South Flux Trap)



MP-1 capsule

- Irradiation conditions per plate type:
  - Three power conditions aid fuel characterization
  - Peak targets for fission density and power density
  - Conditions evaluated on representative reactor’s safety basis fuel node

MP-1 Experiment Description

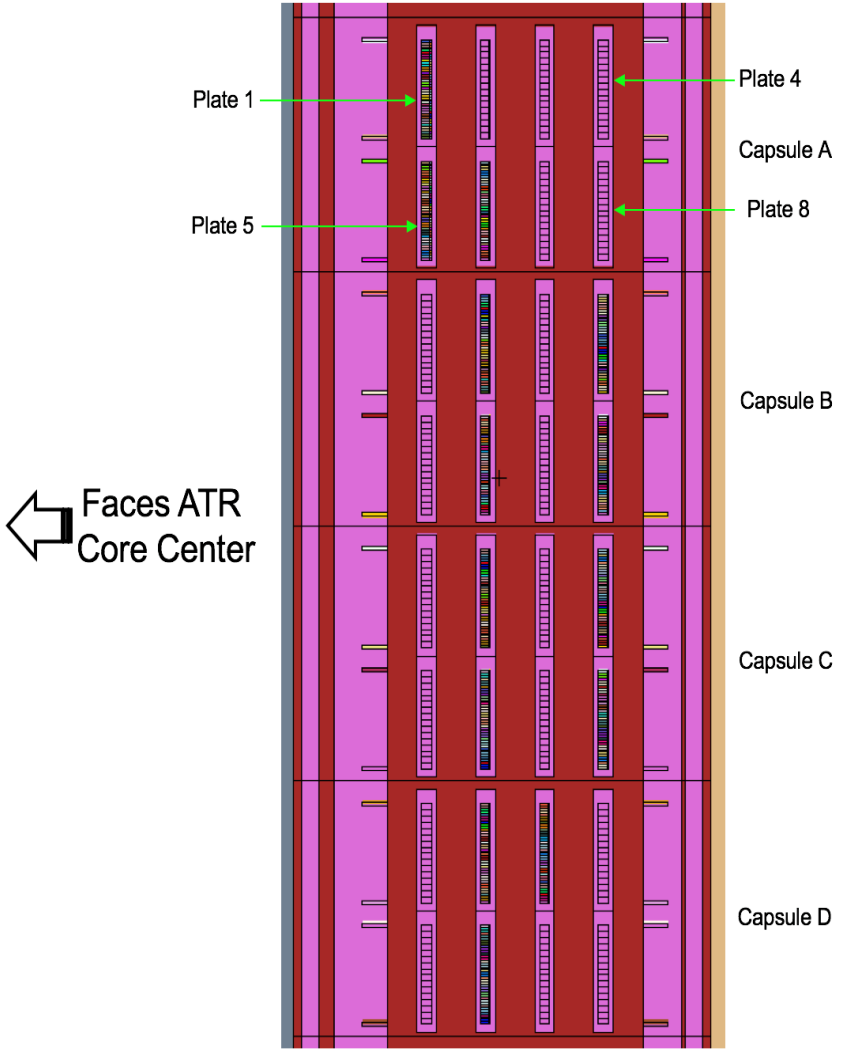
- Fuel qualities:
  - Plate-type with Al cladding
  - U-10Mo monolithic fuel with 19.75% U-235 enrichment
  - Zirconium interlayer
  - Fuel region: 1.905 cm × 8.255 cm × thickness
  - Fully clad plate: 2.540 cm × 10.147 cm × thickness

Plate Performance Requirements

Represented HPRR Plate	Fuel Region Thickness [in. (mm)]	Power Density [kW/cm^3]	Fission Density [fiss/cm^3]
MURR Plate #22 MITR Plate #4, 16	0.025 (0.635)	≥7.1	≥3.6e21
MURR Plate #1 NBSR	0.0085 (0.216)	≥16.3	≥6.2e21

MP-1 Model Description

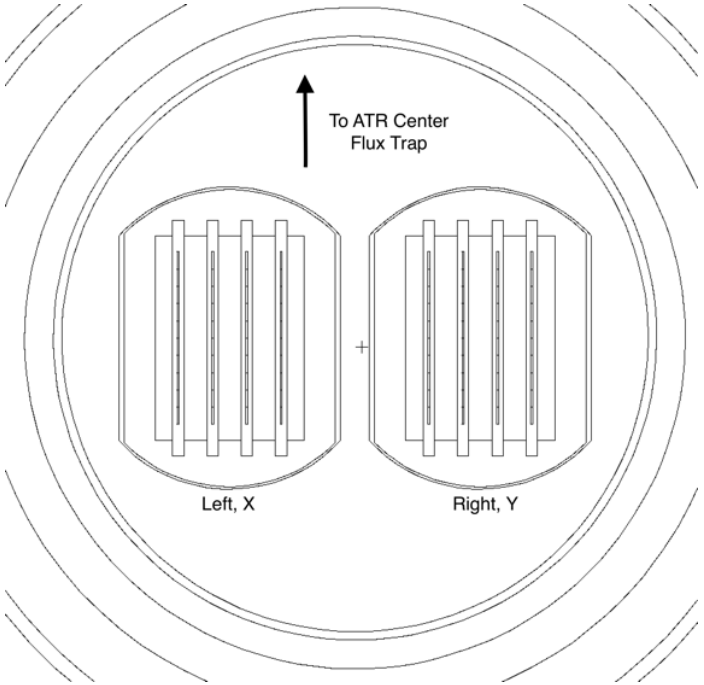
- Goal to demonstrate programmatic requirements were met
- Three-dimensional Monte Carlo N-Particle (MCNP5 1.60) model based on current program drawings
  - Utilizes an ATR full-core model
  - ENDF/B-VII and JENDL-3.2 cross-section libraries
- Depletion using ORIGEN2
  - ATR-specific library
  - Experiment-specific MCNP-generated cross-sections



MP-1 B-11 test train axial cross section
*not to scale

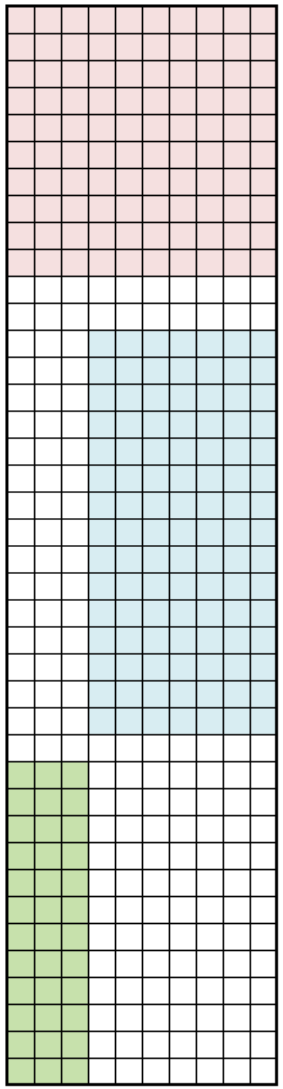
MP-1 Model Description

- 10 × 40 mesh for each fueled plate
  - More accurately track burnup and fission density
  - Aids specific reactor node analysis
    - Averaged anywhere on plate



MCNP model of MP-1 in SFT

NBSR node: 10 x 10
MURR node: 12 x 3
MITR node: 15 x 7



Miniplate 10x40 mesh

MP-1 As-Run Methods

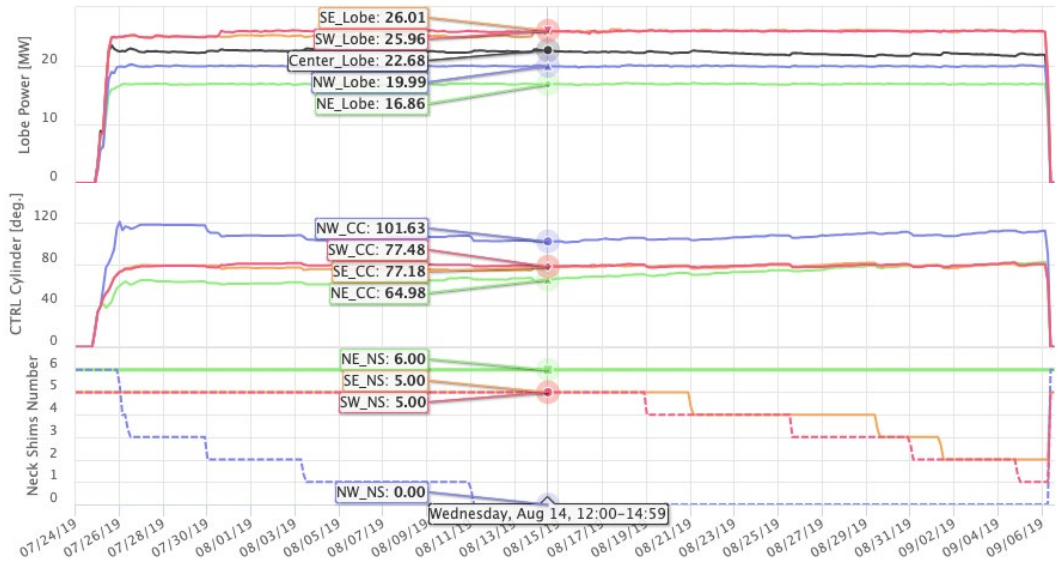
- Use MCNP and ORIGEN to calculate:
  - Beginning of Life (BOL) peak power density
  - End of life (EOL) peak fission density
  - Neutron flux
  - %U-235 depletion
  - Fissions Per Initial Heavy Metal Atom

	A2C 193 (kW/cm³)									
	1	2	3	4	5	6	7	8	9	10
1	5.5	5.4	5.8	5.9	5.8	5.9	5.8	5.6	5.6	5.6
2	5.5	5.3	5.6	5.7	5.4	5.3	5.6	5.5	5.4	5.4
3	5.9	5.7	5.6	5.5	5.8	5.6	5.6	5.7	5.5	5.7
4	6.1	5.8	5.7	5.6	5.9	5.7	5.8	5.8	5.9	6
5	6.3	6	6	5.8	5.8	5.7	5.5	5.8	5.6	6.1
6	6.4	6.2	5.9	6	6	5.8	5.8	6.1	6	6.3
7	6.3	6.1	6.2	5.9	5.9	5.7	5.9	5.8	6	6.4
8	6.5	6.2	6.3	6	6	6	6	6	6	6.5
9	6.4	6.1	6	6	6.1	5.9	6.2	6.3	6.3	6.4
10	6.5	6.3	6	6	6.1	6.1	6.1	6.2	6.2	6.7
11	6.7	6.3	6.2	6.1	6.2	6.1	6.2	6.2	6.3	6.7
12	6.6	6.3	6.5	6.2	6.3	6.2	6.2	6.2	6.3	6.9
13	6.7	6.4	6.2	6.3	6.3	6.3	6.1	6.4	6.6	6.8
14	6.9	6.2	6.6	6.2	6.4	6.2	6.2	6.4	6.5	6.9
15	6.7	6.5	6.3	6.2	6.5	6.4	6.1	6.3	6.5	6.8
16	7.1	6.2	6.4	6.5	6.3	6.5	6.5	6.4	6.4	7.1
17	6.9	6.5	6.5	6.6	6.4	6.2	6.3	6.3	6.4	7.1
18	7.1	6.7	6.6	6.5	6.5	6.3	6.7	6.5	6.6	7
19	7.2	6.5	6.5	6.5	6.6	6.3	6.3	6.4	6.5	6.9
20	7	6.5	6.5	6.5	6.4	6.4	6.3	6.5	6.6	6.9
21	7	6.5	6.6	6.5	6.4	6.5	6.5	6.7	6.6	7
22	7	6.8	6.6	6.5	6.7	6.4	6.5	6.7	6.5	7.2
23	7	6.7	6.4	6.6	6.6	6.5	6.7	6.6	6.8	7.2
24	7.1	6.7	6.5	6.6	6.6	6.7	6.8	6.8	6.5	7.3
25	7.1	6.8	6.4	6.7	6.6	6.6	6.8	6.6	6.8	7.3
26	7.2	6.9	6.7	6.6	6.7	6.7	6.8	6.7	6.9	7.2
27	7.1	6.6	6.9	6.8	6.5	6.7	6.8	6.9	6.7	7.3
28	7.2	6.7	6.9	6.8	6.6	6.7	6.8	6.7	6.7	7.4
29	7.4	6.9	6.7	6.6	6.7	6.9	6.8	6.7	6.7	7.3
30	7.2	6.8	6.6	6.6	6.7	6.7	6.6	6.7	6.9	7.3
31	7.2	6.8	6.7	7	6.9	6.8	6.6	6.9	7.1	6.9
32	7.2	7	6.6	6.7	6.8	6.8	6.7	6.5	6.9	7
33	7.3	7	6.6	6.6	6.5	6.5	6.7	6.7	6.6	7.2
34	7.1	6.6	6.8	6.8	6.6	6.8	6.9	6.7	6.8	7.3
35	7.2	6.7	6.7	6.8	6.5	6.6	6.6	6.8	6.8	7
36	7	6.6	6.7	6.6	6.6	6.4	6.5	6.4	6.5	7
37	6.9	6.6	6.4	6.4	6.6	6.3	6.5	6.6	6.5	6.7
38	6.7	6.4	6.4	6.4	6.5	6.3	6.4	6.2	6.4	6.6
39	6.2	6.1	6.1	6.3	6.2	6.3	6.4	6.3	6.1	6.3
40	6	6.3	6.4	6.4	6.5	6.6	6.5	6.4	6.1	6

An MP-1 Plate Power Density 10x40 mesh at BOL

MP-1 As-Run Methods

- As-built plate dimensions
- ATR fuel element loading
- ATR Surveillance and Data Acquisition System
  - As-run power history and control history
  - Hourly data used to refine depletion timesteps



Reactor data for Cycle 166A-1

POWER HISTORY -- LOBES

Time	Date	N-16 Unconstrained (MW) NW	NE	C	SW	SE		N-16 Constrained (MW) NW	NE	C	SW	SE
1459	07-25-19	19.58	16.73	24.32	25.05	24.89	*	19.01	16.11	23.92	24.38	24.27
1659	07-25-19	19.58	16.68	24.07	25.58	25.34	*	18.84	15.86	23.54	24.70	24.53
1459	07-26-19	20.99	17.71	23.43	26.04	26.04	*	20.20	16.84	22.86	25.11	25.18
1459	07-28-19	21.12	17.96	23.12	26.20	26.17	*	20.05	16.79	22.36	24.94	25.01
1559	07-30-19	20.99	18.10	23.53	27.17	25.99	*	19.95	16.96	22.80	25.95	24.86
1459	08-04-19	20.96	17.92	23.52	27.09	26.21	*	19.87	16.74	22.75	25.82	25.04
2359	08-13-19	21.02	17.85	23.52	26.93	27.04	*	20.07	16.81	22.85	25.81	26.01
1459	08-14-19	21.00	17.98	23.46	27.12	27.13	*	19.93	16.81	22.70	25.86	25.96
1459	08-24-19	20.85	17.94	22.62	27.14	27.06	*	19.86	16.86	21.92	25.99	25.99
1459	09-03-19	20.97	18.02	22.60	27.21	27.10	*	20.01	16.98	21.92	26.10	26.07
0859	09-06-19	20.74	17.97	22.36	26.72	26.79	*	19.74	16.87	21.65	25.55	25.71

REACTOR CONTROL HISTORY

Time	Date	Outer Shims (deg) NW N1-2	SW W3-4	NE W1-2	SE S3-4	NW N3-4	SW E1-2	NE E3-4	SE S1-2	Reg Rods- (in) RR-1	RR-2	Neck Shims NW	NE	SW	SE
1459	07-25-19	81.8	81.4	55.8	55.6	40.2	40.1	54.9	55.2	25.6	47.8	IIIII	IIIII	IIIRII	IIIRII
1659	07-25-19	85.5	86.0	60.4	60.3	42.7	42.8	59.8	59.9	24.1	47.8	IIIII	IIIII	IIIRII	IIIRII
1459	07-26-19	113.5	113.1	75.1	75.0	59.9	59.9	76.0	76.2	29.1	47.8	IIIOOO	IIIII	IIIRII	IIIRII
1459	07-28-19	117.4	117.3	78.0	78.0	62.8	62.7	78.5	78.6	26.0	47.8	IIIOOO	IIIII	IIIRII	IIIRII
1559	07-30-19	106.6	106.3	79.7	80.0	60.2	60.3	75.5	75.4	25.4	47.8	IIOOOO	IIIII	IIIRII	IIIRII
1459	08-04-19	102.9	102.9	78.5	78.5	60.3	60.3	75.1	75.1	26.4	47.8	IOOOOO	IIIII	IIIRII	IIIRII
2359	08-13-19	101.5	101.2	76.8	76.7	64.0	63.5	76.9	76.8	22.8	47.8	OOOOOO	IIIII	IIIRII	IIIRII
1459	08-14-19	101.7	101.9	77.5	77.4	65.0	65.0	77.2	77.2	25.0	47.8	OOOOOO	IIIII	IIIRII	IIIRII
1459	08-24-19	107.4	107.0	79.8	79.9	73.7	73.7	79.0	79.0	20.8	47.8	OOOOOO	IIIII	IIIRIO	IIIRIO
1459	09-03-19	111.1	111.0	80.0	80.2	79.6	79.3	79.3	79.4	23.1	47.8	OOOOOO	IIIII	IIOROO	IIOROO
0859	09-06-19	112.3	112.4	80.2	80.3	82.6	82.7	80.1	80.4	47.8	28.8	OOOOOO	IIIII	IIOROO	IIOROO

Example ASUDAS data for Cycle 166A-1

MP-1 Results

- Performed as-run cycle analysis:

ATR position	164A	164B	166A	# MP-1 Plates
B-10	■	■		14
B-11			■	14
B-12	■			14
South Flux Trap		■	■	32

- Power density goals met for both plate types
- Fission density goals not met
  - Early conclusion due to plate delamination
    - "MP-1 Experiment Recovery Report, Fuel Breach, and Reinsertion Risk Assessment," INL-EXT-20-57170

MP-1 Results

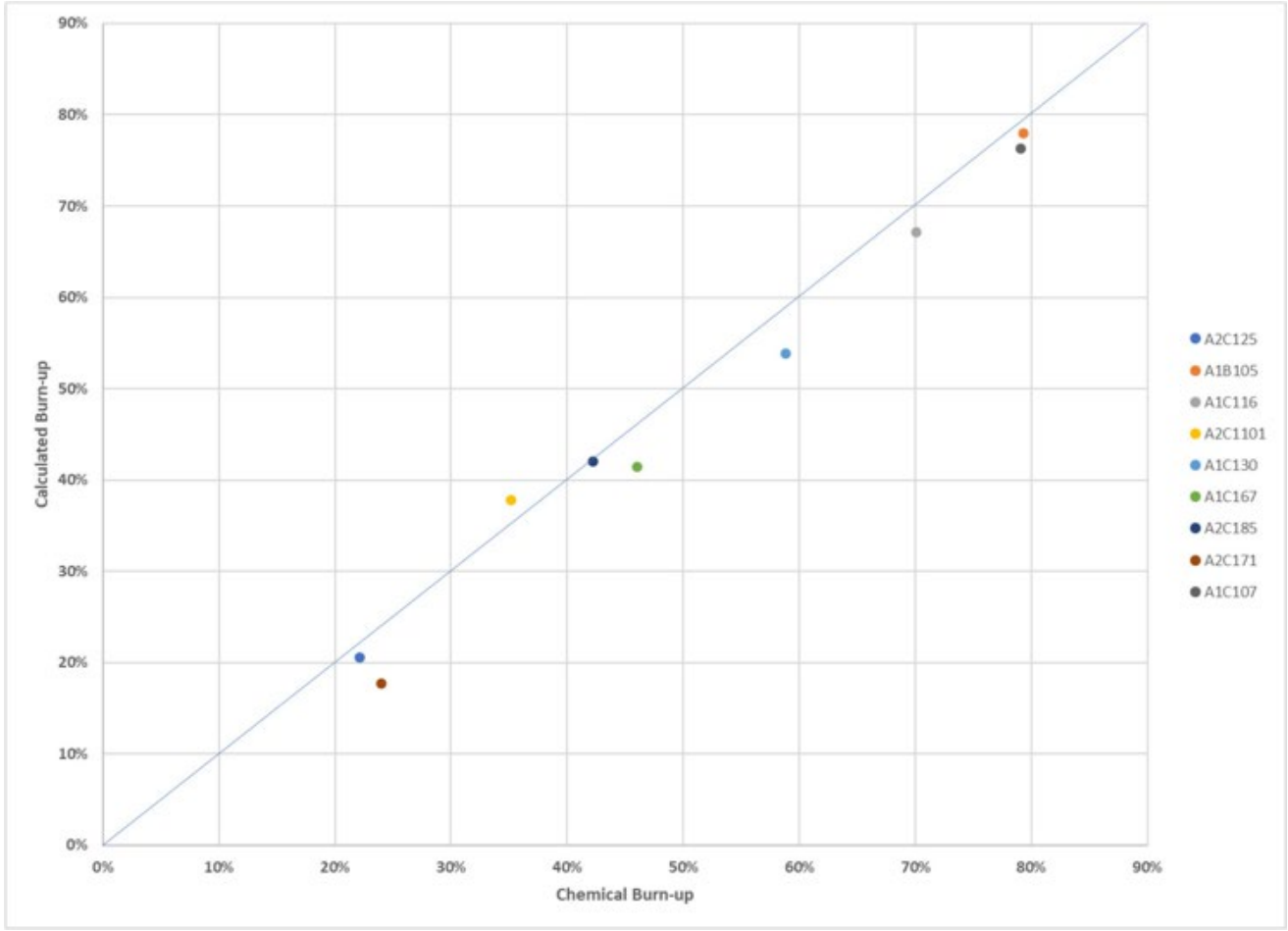

As-Run Peak Power and Fission Density
Power Density [kW/cm3]
35
30
25
20
15
10
5
0
0E+00
1E+21
2E+21
3E+21
4E+21
5E+21
6E+21
7E+21
Fission Density [fiss/cm3]
MURR-22
MITR-4,16
MURR-1
NBSR

MP-1 Validation of Results

- Power density
  - Impossible without actively instrumented experiment
- Fission density
  - EOL isotopics via destructive examination
    - MP-1 Post Irradiation Examination Report
    - Multi-channel inductively coupled plasma mass spectrometry
    - Report states generally within 5% burnup

MP-1 Validation of Results

Calculated Burn-up vs Chemical (measured) Burn-up



* From MP-1 Post Irradiation Examination Report

Acknowledgements

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  - National Technical Lead: Jim Cole
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  - Experiment Manager: Nicholas Meacham
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- Neutronics Contributors: Dong Choe
- Post Irradiation Examination: Adam Robinson, Alex Hanson

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