Design of the University of Missouri Research Reactor Design Demonstration Element (MURR-DDE) Test for Irradiation in the Advanced Test Reactor (ATR)

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— PERMANENT THREAT REDUCTION —

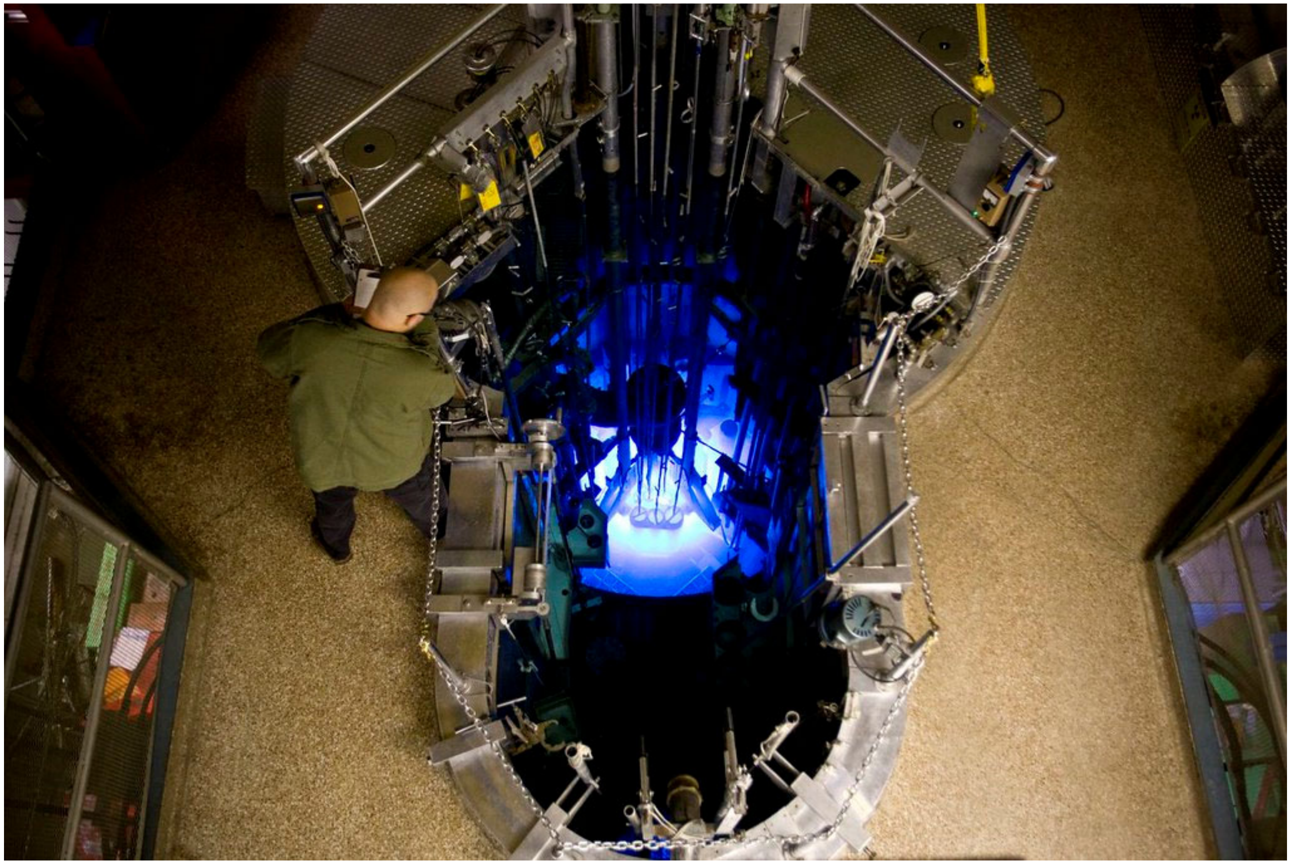
MATERIAL MANAGEMENT AND MINIMIZATION

CONVERT, REMOVE, DISPOSE

Missouri University Research Reactor (MURR)

Highest power university research reactor (10 MWth) in the US

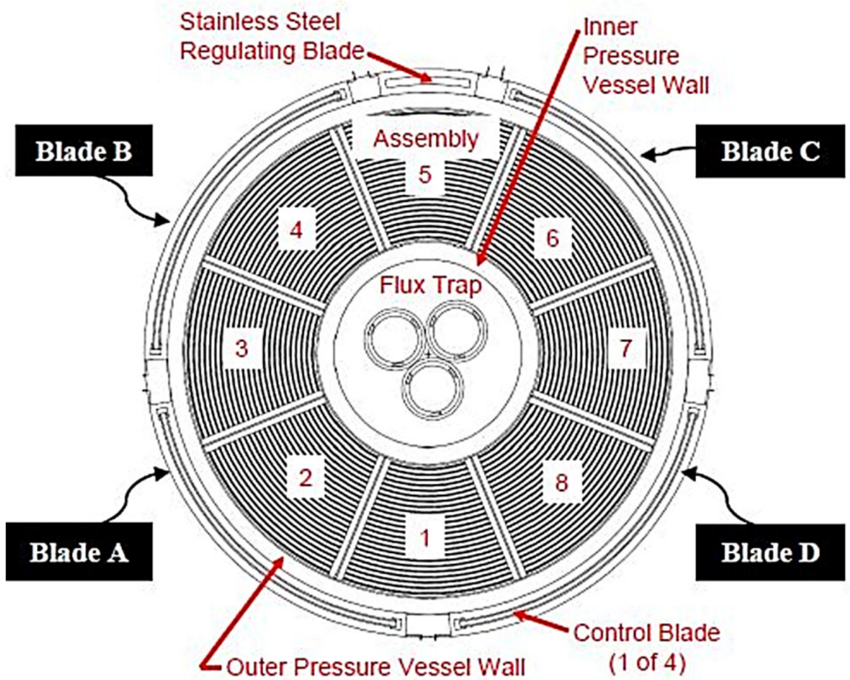
Designed by *Internuclear Company*, Started in 1966, Operates 6.5 days per week, 52 weeks per year



NRC regulated reactor

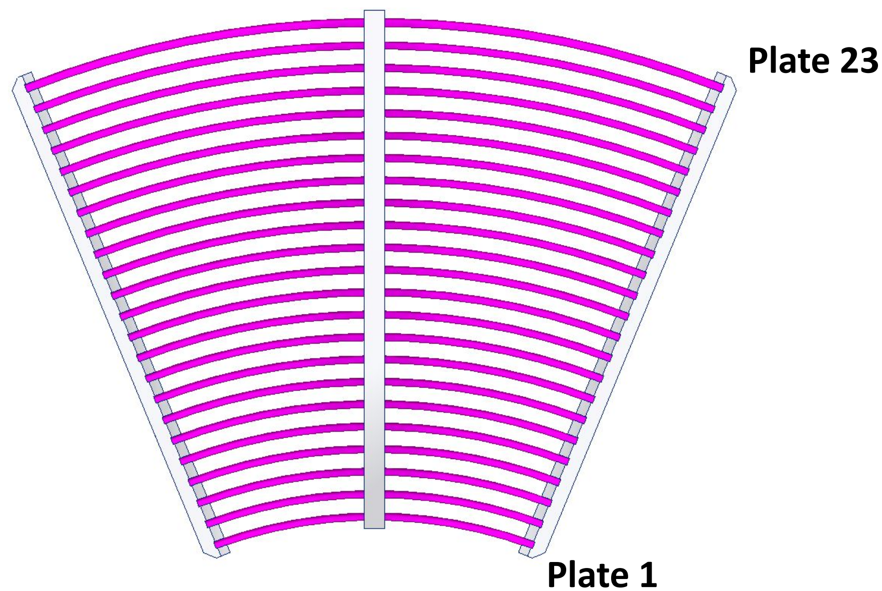
https://www.murr.missouri.edu/people-category/faculty-and-researchers/

MURR Core and Fuel Element



MURR Core Layout

Courtesy of John Stillman (ANL)



MURR LEU Fuel Element

Courtesy of Greg Housley (INL)

Two Step Approach for converting NRC reactors to LEU Fuel

	Main Steps	Key Tests*	Scale	Key Deliverable	Comments
1	**Generic fuel qualification**	MP-2	Miniplate	Fuel Qualification Report to NRC: • Physical evidence of acceptable in-reactor performance of LEU fuel • Summary of fuel properties and performance data	No direct tie to safety bases of specific reactors
		FSP-1	Large size plate		
		ET-1	Element		
2	**Licensing of fuel for use in NRC reactors**	MURR DDE	Prototypic Element Design	LEU conversion submittal to NRC: • Review of the Tech Basis for properties and fuel performance data • final Safety Analysis Report (SAR)	Direct tie to safety bases of specific reactors

* All fuel is made by BWX Technologies, Inc.

What is DDE?

- Safety bases of NRC reactors prohibit testing of LTAs in the core
- Alternative solution?
    - Design Demonstration Element! = Slightly modified MURR fuel element to be tested in ATR
        - Trying to be as prototypic as possible
        - Modifications are driven either by the need for inspections or by test reactor constraints
        - The plan is to identify all deltas between MURR LEU element and MURR DDE and evaluate their impact

MURR-DDE Test Objectives

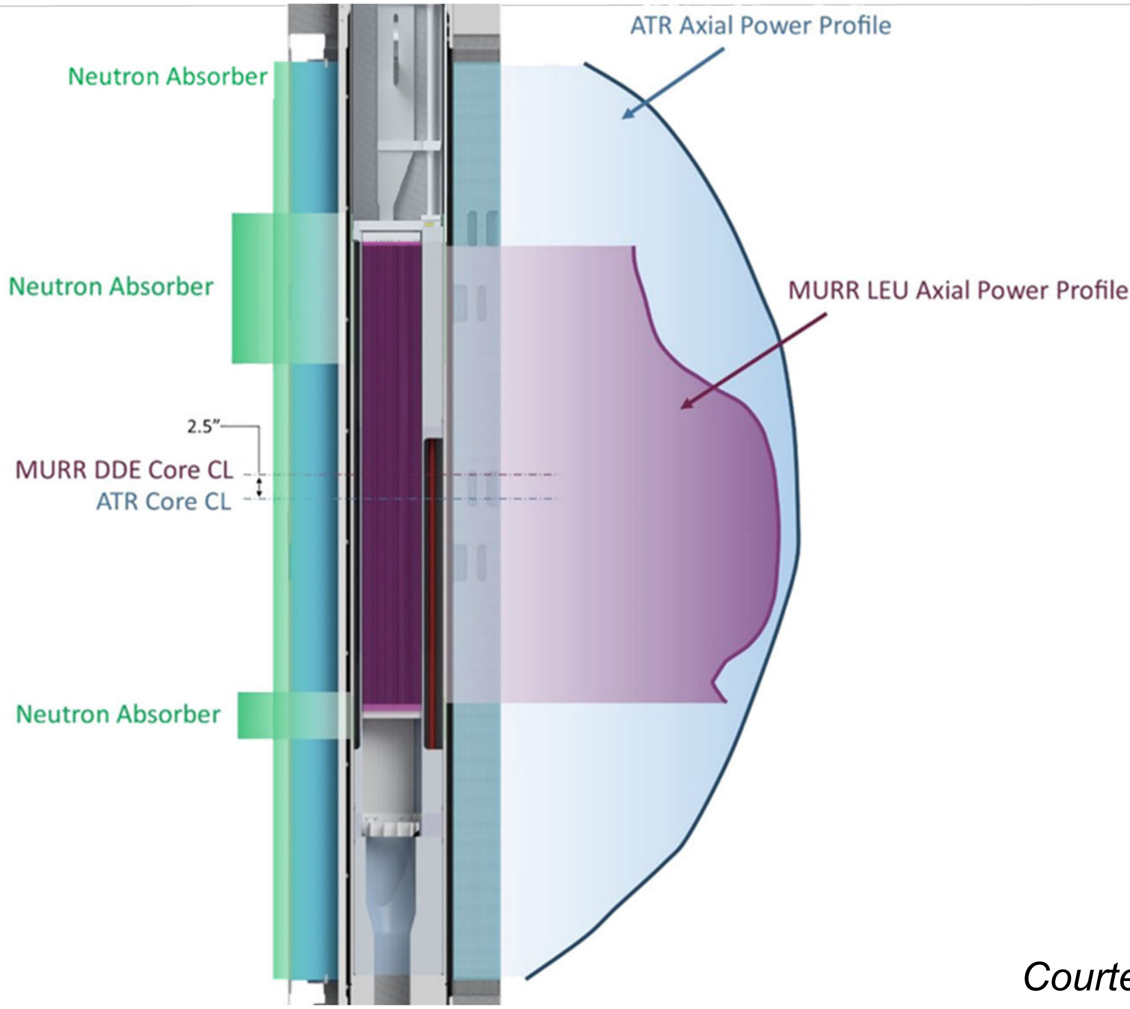
- Confirm acceptable performance (i.e., geometric stability, structural integrity, and stable and predictable behavior during the entire course of irradiation) of the new LEU U-10Mo MURR fuel element at conditions prototypic for MURR (heat flux, volumetric power, and fission density, flow rate)
- Confirm resistance to potential failure modes for reactor-specific plate and element design at full scale (fission gradients, thin-clad structural stability, thermo-mechanical and hydraulic stresses)
- Demonstrate fabrication by producing the plates and elements as demonstration products to the requirements of a conversion-element specification
- Provide confidence in the LEU fuel designs prior to conversion

Design Inputs = a.k.a Targets

Neutronics parameters

Plate	BOL Peak Power Density, kW/cm^3	EOL Peak Fission Density, $\times 10^{21}$ $fiss/cm^3$
1	14.40	3.37
2	10.61	2.79
22	7.40	2.07
23	9.69	2.59

Axial Power Profiles



- MURR and ATR have different lengths and power distributions
- MURR DDE centerline was raised 2.5" above ATR core centerline
- Hf filters were used to make MURR DDE power distribution more prototypic

Courtesy of Greg Housley (INL)

Test Assembly

Courtesy of Greg Housley (INL)

MURR DDE Element

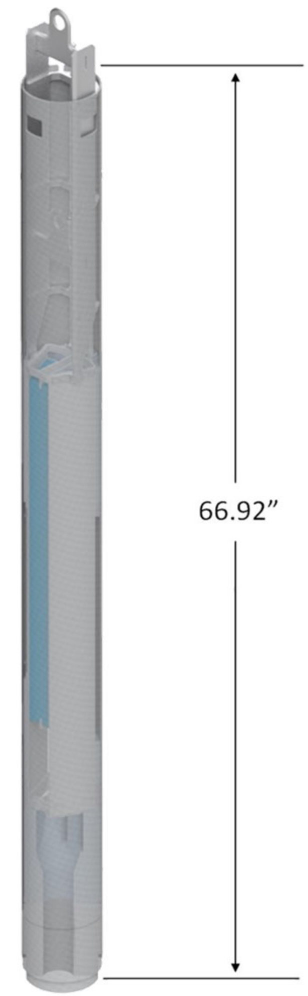
~31 lbs

MURR DDE Filler Assembly

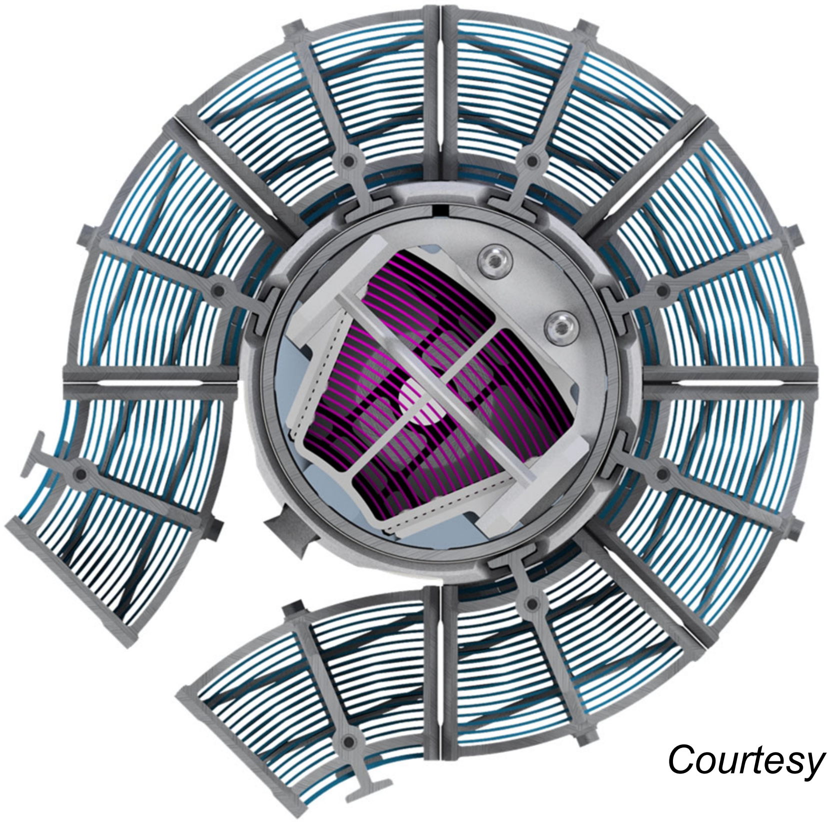
~25 lbs

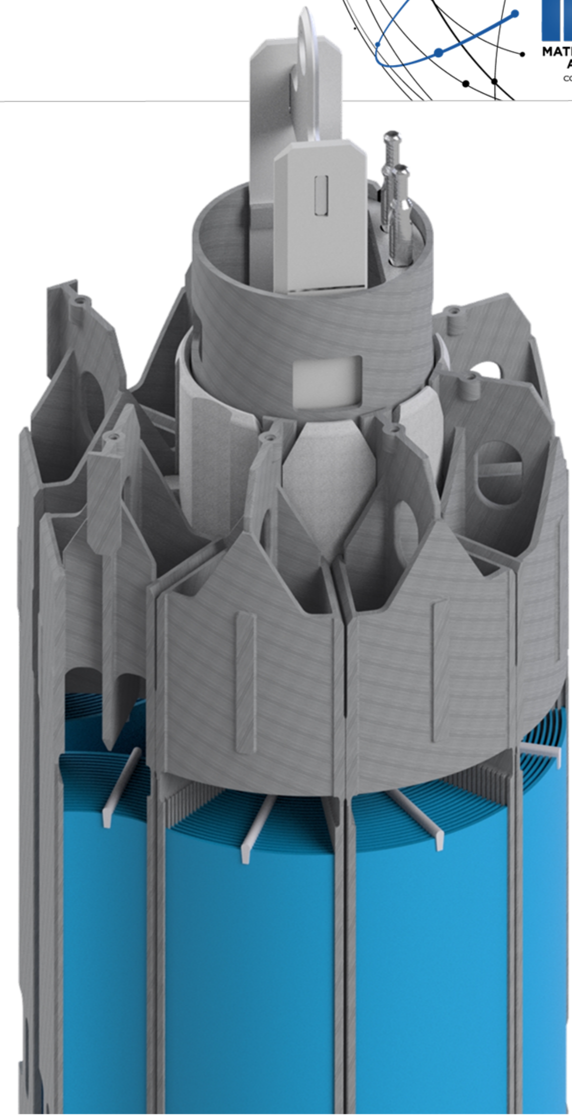
MURR DDE Hafnium Basket

~20 lbs



MURR DDE in North East Flux Trap (NEFT)





Courtesy of Greg Housley (INL)

Challenges in Design Space

— PERMANENT THREAT REDUCTION —
M3
MATERIAL MANAGEMENT AND MINIMIZATION
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Lack of experience - fuel elements are not routinely tested in ATR

Experiment	Test Position	Year	Grams of U235	Flow rate gpm
KJRR	NEFT	2015	620	473 total (2 pump)
FSP-1	NEFT	2023	337	467 total (2 pump)
ET-1 (like ATR fuel)	Driver Fuel	2024	1648	557 (2 pump) 628 (3 pump)
MURR DDE	NEFT	2026	1507 (~$4 worth)	~520 total (2 pump)

Root of the evil:

High U loading → neutronics challenges

High flow rates → hydraulics challenges

Balancing Act – Numerous Neutronics Iterations

Requirements

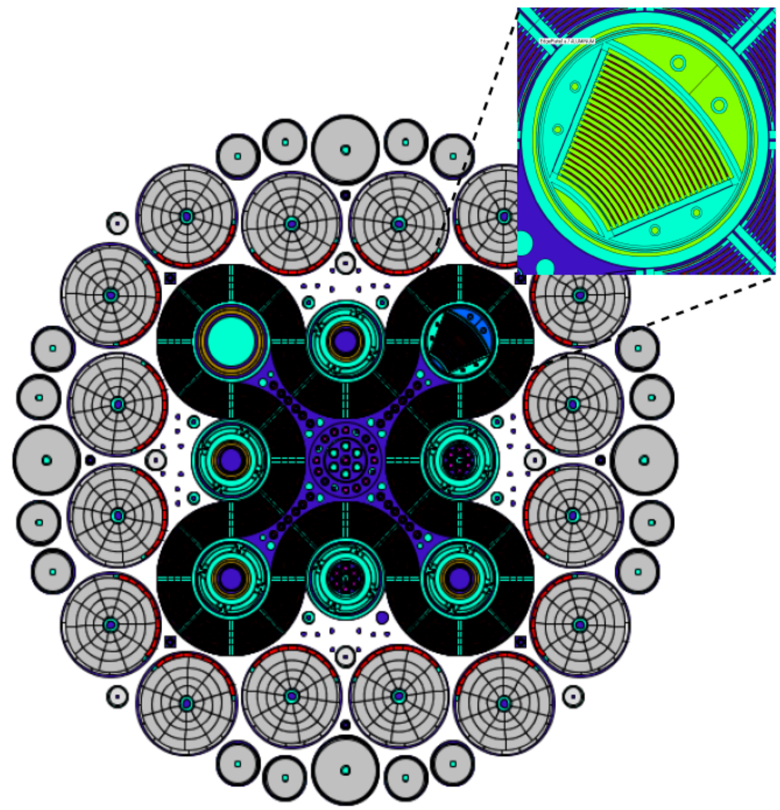
1. Startup the reactor with the OSCCs in a reasonable position (i.e., >= 30 degrees)
    - 0 degrees – absorber is fully in the core (flux suppressed)
2. Achieve desired power splits (core tilt) in the cycle:
    - normal cycle splits
    - high power cycle splits (new, introduced further complexity)
3. Sustain desired cycle length
4. Not exceed fission density SAR limits in driver fuel elements
5. Meet experiment targets

Knobs to turn:

- driver fuel loading
- lobe power levels
- absorber in the experiment

MURR DDE Neutronics Analysis Using MC21

- Monte Carlo neutral particle transport code developed by Naval Nuclear Laboratory (NNL).
- Highly optimized for reactor core physics analysis.
- ENDF/B-VIII data processed by NDEX code.
- Supports reactor feedback mechanisms (e.g., depletion, thermal feedback, xenon feedback, photon/neutron heating).
- Critical shim position search through Python scripts.
- PUMA-API can flexibly handle complex geometry/material definitions and transfer to MC21 inputs.
- PUMA ATR model:
  - Modularized approach allows for building experiment models into a single java file/class.
  - Experiment loading is controlled through a simple text file.
  - And more.



Courtesy of Hikaru Hiruta (INL)

Proposed Irradiation Plan

- Irradiation plan (lobe powers in MW):
  - Two 59-day cycles.
  - BOC NE lobe power: 18 MW (Cycle 1), 18 MW (Cycle 2).
  - Gradually increase NE lobe power (to 21 MW) toward EOC.
  - High power (30 MW) in SE.

	NW	NE	C	SW	SE	Total
Cycle 1 (59 days)	20	**18-21**	23	23	30	114-117
Cycle 2 (59 days)	20	**18-21**	23	23	30	114-117

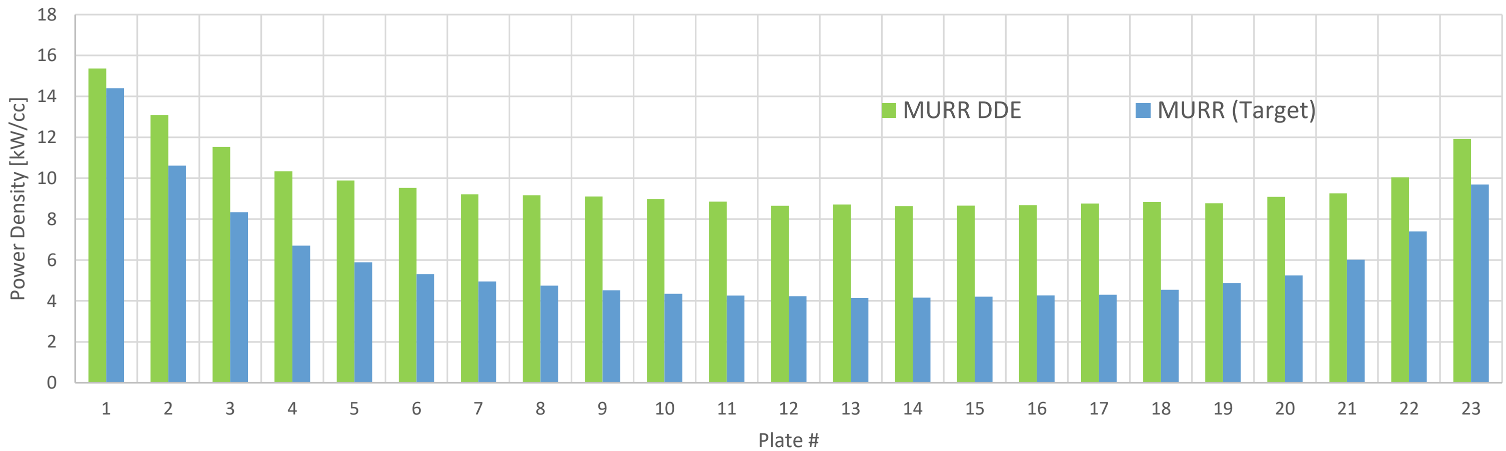
- Use a similar fuel loading in both Cycles 1 and 2.

Courtesy of Hikaru Hiruta (INL)

Plate-by-Plate Peak Power Density

- Peak Power Density (kW/cm^3)

Peak Power Density [kW/cc]		
Plate #	MURR DDE	MURR (Target)
1	15.362	14.400
2	13.088	10.610
3	11.532	8.340
4	10.339	6.700
5	9.884	5.890
6	9.523	5.310
7	9.213	4.950
8	9.170	4.750
9	9.107	4.520
10	8.975	4.350
11	8.856	4.260
12	8.650	4.230
13	8.715	4.140
14	8.637	4.160
15	8.655	4.210
16	8.681	4.270
17	8.757	4.300
18	8.834	4.540
19	8.775	4.870
20	9.086	5.250
21	9.261	6.010
22	10.041	7.400
23	11.923	9.690



Courtesy of Hikaru Hiruta (INL)

Radial BOL Power Density Distribution of Limiting Plates

Courtesy of Hikaru Hiruta (INL)

- MURR (Target) Power Density (kW/cm^3)

Plate 1

Distance from the top of fuel (inches)	1	2	3	4	5	6	7	8	9
0.5	4.20	3.67	3.71	3.47	3.76	3.66	3.54	3.54	3.61
1.5	4.03	3.78	3.80	3.73	3.53	3.80	3.54	3.75	3.74
2.5	4.66	4.63	4.40	4.43	3.98	4.52	4.19	4.47	4.68
3.5	5.50	5.45	5.39	5.41	5.04	5.15	5.52	5.37	5.43
4.5	6.67	6.10	6.36	6.53	6.07	6.42	6.39	6.30	6.55
5.5	7.38	7.26	7.08	7.14	6.70	7.35	7.11	7.27	7.41
6.5	8.25	8.14	7.85	7.76	7.49	7.98	7.90	8.08	8.15
7.5	9.17	8.59	8.92	8.66	8.12	8.71	8.33	8.65	8.99
8.5	10.13	9.69	9.61	9.65	9.47	9.93	9.42	9.19	9.94
9.5	11.32	10.66	10.42	10.62	10.03	10.74	10.84	10.71	10.93
10.5	12.18	11.97	11.54	11.73	11.00	11.71	11.79	11.86	11.98
11.5	12.84	12.56	12.50	12.35	11.70	13.06	12.61	12.77	13.08
12.5	13.73	13.72	13.09	13.45	12.53	12.86	12.87	13.24	13.43
13.5	14.32	13.64	13.22	13.27	12.92	13.28	13.83	13.62	13.94
14.5	14.40	13.67	13.22	13.34	13.15	13.53	13.59	13.74	13.86
15.5	13.69	13.42	13.27	12.90	12.64	13.77	13.14	13.63	13.70
16.5	13.33	12.68	12.50	12.87	12.33	12.65	12.60	12.96	13.04
17.5	12.81	12.60	12.12	12.17	11.30	11.79	11.55	11.86	12.25
18.5	11.98	11.43	11.37	11.44	11.02	10.99	11.19	11.75	11.66
19.5	11.13	10.68	10.73	11.05	10.43	10.23	10.35	10.46	10.81
20.5	10.60	10.41	10.06	10.20	9.44	9.80	9.74	10.48	10.13
21.5	9.90	9.55	9.12	9.17	9.06	9.21	9.37	9.43	9.47
22.5	8.99	8.67	8.84	8.47	8.05	8.14	7.96	8.37	8.58
23.5	9.11	8.91	8.89	8.85	8.35	8.92	8.95	8.90	9.07

Plate 2

Distance from the top of fuel (inches)	1	2	3	4	5	6	7	8	9
0.5	3.10	2.70	2.57	2.65	2.49	2.66	2.71	2.73	2.96
1.5	2.94	2.62	2.59	2.60	2.51	2.61	2.57	2.62	2.85
2.5	3.39	3.25	3.17	3.12	2.99	3.00	3.05	3.17	3.43
3.5	4.21	3.81	3.65	3.88	3.41	3.56	3.60	3.71	3.98
4.5	4.64	4.40	4.37	4.31	4.19	4.21	4.34	4.52	4.78
5.5	5.50	5.06	4.85	4.81	4.63	4.76	4.81	4.92	5.47
6.5	6.12	5.59	5.60	5.43	5.23	5.54	5.53	5.75	6.11
7.5	6.87	6.20	6.08	6.03	5.96	6.12	6.23	6.33	6.85
8.5	7.58	6.95	6.85	6.82	6.68	6.79	6.99	7.11	7.56
9.5	8.37	7.76	7.60	7.56	7.32	7.42	7.66	7.74	8.57
10.5	9.12	8.51	8.16	8.08	7.64	8.26	8.19	8.27	8.99
11.5	9.67	8.94	8.76	8.75	8.28	8.79	8.61	8.97	9.82
12.5	10.35	9.57	9.19	9.21	8.68	9.17	9.10	9.36	10.11
13.5	10.48	9.73	9.40	9.34	8.84	9.40	9.49	9.84	10.38
14.5	10.60	9.55	9.34	9.28	8.98	9.30	9.45	9.75	10.32
15.5	10.61	9.52	9.14	9.11	8.73	9.30	9.24	9.48	10.31
16.5	10.04	9.38	8.91	8.87	8.44	9.07	8.89	9.17	9.89
17.5	9.81	8.98	8.52	8.67	8.21	8.46	8.72	8.85	9.50
18.5	9.15	8.32	7.89	8.09	7.72	7.97	7.99	8.53	8.97
19.5	8.50	7.76	7.75	7.71	7.11	7.50	7.52	7.82	8.47
20.5	8.10	7.24	7.03	6.97	6.66	7.07	7.13	7.28	7.95
21.5	7.20	6.72	6.69	6.56	6.19	6.45	6.45	6.60	7.16
22.5	6.74	6.11	5.88	5.72	5.56	5.81	5.82	6.04	6.53
23.5	7.26	6.54	6.26	6.39	6.01	6.24	6.17	6.57	7.19

Plate 22

Distance from the top of fuel (inches)	1	2	3	4	5	6	7	8	9
0.5	0.78	0.75	0.66	0.75	0.90	0.78	0.66	0.73	0.81
1.5	0.77	0.65	0.68	0.75	0.89	0.74	0.72	0.70	0.75
2.5	0.89	0.91	0.86	0.94	1.03	0.89	0.80	0.78	0.89
3.5	1.09	1.02	1.01	1.06	1.20	1.05	0.95	0.96	1.04
4.5	1.29	1.11	1.16	1.24	1.41	1.23	1.18	1.08	1.24
5.5	1.42	1.39	1.37	1.42	1.72	1.44	1.36	1.36	1.46
6.5	1.71	1.56	1.55	1.79	2.03	1.75	1.66	1.67	1.91
7.5	2.27	2.14	2.13	2.26	2.56	2.23	2.14	2.15	2.25
8.5	3.83	3.44	3.47	3.28	3.21	3.23	3.24	3.38	3.86
9.5	5.35	4.70	4.31	4.17	3.93	4.17	4.48	4.56	5.21
10.5	6.02	5.17	5.03	4.70	4.47	4.81	5.00	5.19	5.84
11.5	6.64	5.64	5.48	5.08	4.92	5.14	5.64	5.73	6.58
12.5	6.73	6.02	5.74	5.51	5.08	5.45	5.74	5.98	6.74
13.5	7.32	6.29	6.18	5.66	5.39	5.59	5.83	5.97	7.13
14.5	7.32	6.44	6.00	5.76	5.48	5.67	6.03	6.38	7.40
15.5	7.23	6.23	5.87	5.73	5.49	5.75	6.09	5.95	7.18
16.5	7.23	6.21	6.00	5.73	5.39	5.55	5.68	6.17	7.02
17.5	7.05	6.06	5.80	5.46	5.25	5.56	5.59	6.01	6.83
18.5	6.59	5.78	5.58	5.24	4.94	5.22	5.36	5.86	6.51
19.5	6.13	5.28	5.22	4.94	4.79	4.95	5.33	5.27	6.28
20.5	5.83	4.95	4.90	4.51	4.48	4.58	4.71	4.95	5.81
21.5	5.27	4.50	4.29	4.20	3.98	4.14	4.22	4.39	5.07
22.5	4.63	3.99	4.00	3.72	3.57	3.65	3.92	4.06	4.69
23.5	5.54	4.52	4.30	4.01	3.92	3.94	4.12	4.36	4.95

Plate 23

Distance from the top of fuel (inches)	1	2	3	4	5	6	7	8	9
0.5	0.82	0.69	0.67	0.87	1.10	0.89	0.76	0.84	0.80
1.5	0.75	0.65	0.73	0.88	1.15	0.85	0.73	0.75	0.75
2.5	0.95	0.85	0.88	1.03	1.30	1.01	0.81	0.85	0.89
3.5	1.12	1.02	1.06	1.23	1.59	1.17	0.98	1.07	1.14
4.5	1.25	1.19	1.20	1.43	1.81	1.51	1.18	1.17	1.24
5.5	1.62	1.47	1.47	1.61	2.23	1.69	1.40	1.35	1.48
6.5	1.84	1.72	1.75	2.11	2.63	2.05	1.82	1.79	1.83
7.5	2.66	2.48	2.56	2.80	3.32	2.67	2.56	2.47	2.52
8.5	4.79	4.56	4.43	4.50	4.56	4.40	4.25	4.42	4.70
9.5	6.76	6.42	6.12	5.96	5.66	5.86	6.12	6.21	6.58
10.5	8.07	7.53	7.04	6.88	6.48	6.80	7.14	7.30	7.77
11.5	8.57	8.08	8.06	7.43	7.00	7.35	7.87	8.14	8.48
12.5	9.06	8.48	8.31	7.93	7.44	7.87	8.31	8.37	9.03
13.5	9.43	8.98	8.52	8.27	7.74	8.08	8.55	8.56	9.12
14.5	9.32	8.97	8.68	8.31	7.93	8.18	8.62	8.62	9.45
15.5	9.69	8.78	8.73	8.32	8.02	8.40	8.67	8.77	9.57
16.5	9.62	8.95	8.74	8.19	7.93	8.17	8.55	9.06	9.17
17.5	9.25	8.66	8.16	7.98	7.49	8.01	8.33	8.54	9.13
18.5	8.61	8.39	8.00	7.57	7.20	7.48	8.00	8.47	8.79
19.5	8.12	7.56	7.39	7.21	6.79	7.25	7.55	7.52	8.29
20.5	7.77	7.13	6.76	6.74	6.50	6.72	6.94	7.35	7.65
21.5	7.03	6.56	6.35	6.13	5.87	6.13	6.38	6.26	6.80
22.5	6.25	5.76	5.91	5.56	5.31	5.55	5.51	5.86	6.11
23.5	6.69	6.08	5.99	5.73	5.53	5.59	5.68	6.15	6.63

- MURR DDE Power Density (kW/cm^3)

Plate 1

Distance from the top of fuel (inches)	1	2	3	4	5	6	7	8	9
0.5	4.97	4.84	5.26	5.14	4.93	5.18	5.06	4.79	4.81
1.5	4.54	4.86	4.67	4.64	4.85	4.67	4.61	4.60	4.51
2.5	5.20	5.10	5.06	5.06	5.27	5.14	4.97	4.90	4.71
3.5	5.49	5.48	5.49	5.49	5.42	5.61	5.47	5.34	5.12
4.5	5.95	6.04	6.05	6.21	6.33	5.94	5.84	6.03	5.73
5.5	7.21	7.33	7.17	7.31	7.28	7.42	7.23	7.19	6.95
6.5	10.24	9.66	9.60	9.33	9.09	9.49	9.34	9.40	10.02
7.5	11.90	11.10	10.82	10.62	10.78	10.63	10.77	10.66	11.39
8.5	12.63	12.17	11.66	11.79	11.47	11.36	11.58	11.80	12.13
9.5	13.61	12.70	12.43	12.20	12.27	11.79	11.97	12.28	13.12
10.5	14.28	12.85	12.78	12.50	12.34	12.82	12.56	12.66	13.94
11.5	14.59	13.56	13.44	12.95	12.76	13.31	12.98	13.57	14.02
12.5	14.60	13.83	13.51	13.17	13.13	13.15	13.31	13.63	14.74
13.5	15.15	13.98	13.56	13.55	13.42	13.00	13.26	13.46	14.53
14.5	15.36	14.03	13.67	13.70	13.40	13.42	13.46	13.58	14.71
15.5	14.94	13.95	13.99	13.82	13.34	12.84	13.20	13.38	14.63
16.5	15.26	14.03	13.11	13.41	13.60	13.50	13.23	13.52	14.63
17.5	14.66	13.96	13.08	13.02	13.13	12.70	13.44	13.48	13.91
18.5	14.77	13.52	13.05	12.80	12.46	12.59	12.73	12.91	13.96
19.5	13.71	12.85	12.54	12.51	12.40	12.33	12.60	12.71	13.29
20.5	13.16	12.46	12.03	12.11	11.73	11.81	11.94	11.98	12.82
21.5	12.92	11.72	11.62	11.25	11.31	11.32	11.32	11.50	12.33
22.5	12.17	11.44	10.97	10.54	10.41	10.44	10.98	11.10	11.72
23.5	11.36	10.80	10.98	10.66	10.60	10.78	10.72	10.67	10.76

Plate 2

Distance from the top of fuel (inches)	1	2	3	4	5	6	7	8	9
0.5	4.47	4.44	4.63	4.66	4.72	4.45	4.31	4.42	4.25
1.5	4.11	4.03	4.02	4.14	4.03	3.92	3.97	3.97	4.02
2.5	4.48	4.39	4.30	4.33	4.25	4.26	4.37	4.27	4.43
3.5	4.96	4.79	4.79	4.68	4.63	4.71	4.60	4.56	4.65
4.5	5.39	5.22	5.16	5.15	5.17	5.22	5.19	4.97	5.18
5.5	6.59	6.19	6.13	6.12	6.00	6.12	6.20	6.07	6.22
6.5	8.95	8.29	7.86	7.67	7.58	7.51	7.64	7.73	8.63
7.5	10.17	9.03	8.78	8.80	8.62	8.48	8.65	8.94	9.94
8.5	11.14	10.01	9.43	9.10	9.13	9.09	9.11	9.48	10.65
9.5	11.75	10.40	9.79	9.41	9.57	9.67	9.77	9.99	11.25
10.5	12.27	10.68	10.14	10.06	9.77	9.83	10.01	10.58	11.90
11.5	12.63	10.91	10.20	9.92	10.21	10.15	10.26	10.80	11.78
12.5	12.99	11.31	10.63	10.51	10.49	10.35	10.39	10.71	12.52
13.5	13.02	11.30	10.93	10.58	10.54	10.73	10.45	11.39	12.46
14.5	12.83	11.43	11.13	10.75	10.62	10.48	10.76	11.13	12.40
15.5	13.09	11.53	10.72	10.40	10.32	10.49	10.59	11.08	12.60
16.5	13.04	11.37	10.95	10.40	10.39	10.67	10.58	11.05	12.60
17.5	12.85	11.33	10.54	10.25	10.11	10.08	10.48	10.98	12.22
18.5	12.33	10.92	10.38	10.03	9.94	9.90	10.23	10.77	11.96
19.5	11.97	10.65	9.98	9.87	9.62	9.70	9.84	10.24	11.52
20.5	11.52	10.05	9.57	9.62	9.50	9.35	9.47	9.52	10.90
21.5	10.89	9.55	9.26	8.85	8.76	8.93	8.88	9.36	10.55
22.5	10.10	9.23	8.60	8.49	8.37	8.43	8.47	8.85	10.02
23.5	10.01	9.26	9.20	9.01	8.93	8.77	9.17	8.98	9.67

Plate 22

Distance from the top of fuel (inches)	1	2	3	4	5	6	7	8	9
0.5	2.74	2.67	2.49	2.61	2.56	2.50	2.53	2.51	2.65
1.5	2.64	2.44	2.30	2.22	2.20	2.18	2.24	2.31	2.55
2.5	2.87	2.61	2.52	2.45	2.36	2.39	2.46	2.53	2.72
3.5	3.16	2.83	2.72	2.65	2.62	2.64	2.67	2.78	3.10
4.5	3.46	3.13	3.05	2.95	2.89	2.89	2.97	3.06	3.30
5.5	4.33	3.76	3.50	3.38	3.29	3.38	3.54	3.60	4.13
6.5	5.77	4.80	4.40	4.01	3.78	3.92	4.19	4.60	5.48
7.5	6.52	5.46	4.88	4.46	4.20	4.37	4.78	5.16	6.30
8.5	7.30	5.85	5.42	4.87	4.64	4.81	5.31	5.78	6.95
9.5	7.93	6.38	6.01	5.56	5.33	5.43	5.74	6.24	7.52
10.5	8.66	7.49	6.98	6.80	6.65	6.73	7.00	7.22	8.46
11.5	9.37	8.08	7.66	7.51	7.59	7.33	7.23	7.85	9.11
12.5	9.95	8.41	7.90	7.78	7.87	7.68	7.89	8.02	9.59
13.5	10.03	8.41	8.22	7.97	8.02	7.89	7.91	8.18	9.74
14.5	10.04	8.45	8.14	7.90	8.02	7.83	7.84	8.19	9.70
15.5	9.86	8.46	8.04	7.94	8.03	7.77	7.85	8.29	9.60
16.5	10.01	8.21	7.95	7.82	8.02	7.78	7.82	8.30	9.64
17.5	9.82	8.33	7.88	7.73	7.74	7.66	7.60	7.93	9.56
18.5	9.28	8.03	7.66	7.42	7.62	7.37	7.44	7.77	9.09
19.5	8.93	7.68	7.23	7.24	7.35	7.15	7.21	7.55	8.72
20.5	8.50	7.15	6.91	6.94	7.08	6.86	6.72	7.15	8.25
21.5	8.15	6.96	6.56	6.50	6.58	6.44	6.48	6.71	7.92
22.5	7.50	6.47	6.16	6.13	6.20	6.00	6.00	6.26	7.33
23.5	7.30	6.67	6.81	7.01	7.40	6.98	6.49	6.40	7.13

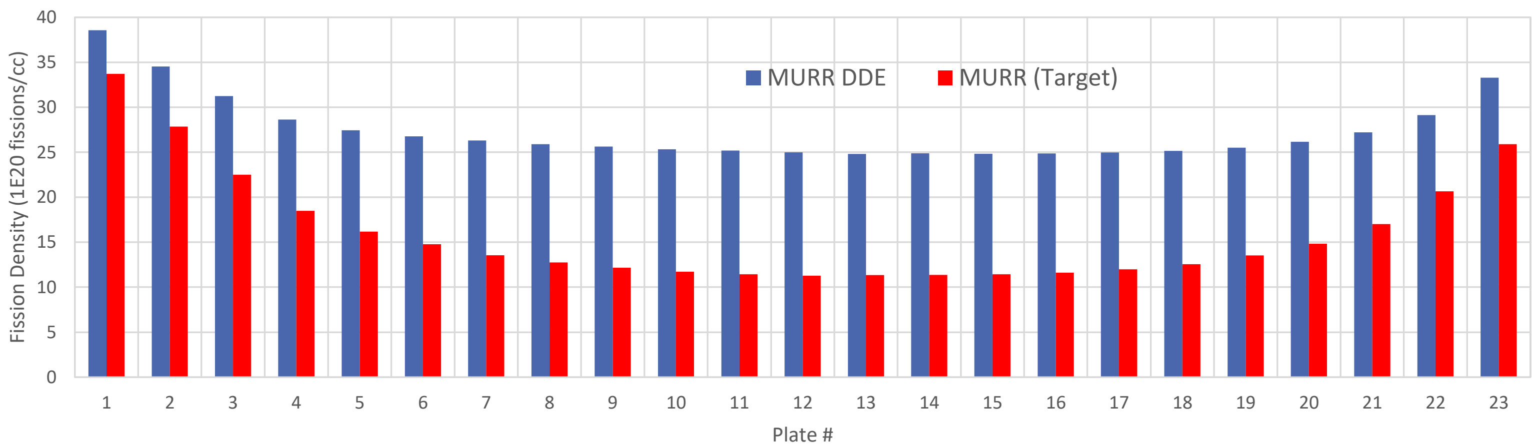
Plate 23

Distance from the top of fuel (inches)	1	2	3	4	5	6	7	8	9
0.5	2.72	2.60	2.59	2.68	2.72	2.67	2.63	2.61	2.58
1.5	2.78	2.54	2.49	2.44	2.40	2.41	2.37	2.46	2.63
2.5	2.95	2.79	2.69	2.61	2.58	2.58	2.57	2.67	2.82
3.5	3.21	3.04	2.97	2.88	2.83	2.79	2.88	2.95	3.14
4.5	3.59	3.38	3.33	3.25	3.17	3.20	3.29	3.32	3.46
5.5	4.44	4.11	4.05	3.75	3.64	3.71	3.86	3.96	4.27
6.5	6.14	5.42	4.91	4.59	4.43	4.50	4.84	5.16	6.02
7.5	7.09	6.20	5.69	5.23	5.02	5.10	5.57	6.07	6.96
8.5	7.94	6.86	6.43	5.81	5.60	5.77	6.24	6.79	7.62
9.5	9.15	7.75	7.52	6.75	6.51	6.68	7.10	7.57	8.73
10.5	10.40	9.31	9.01	9.08	9.06	8.96	8.91	9.23	9.86
11.5	11.14	10.21	10.19	10.27	10.63	10.10	9.96	10.11	10.65
12.5	11.72	10.45	10.40	10.77	11.13	10.59	10.13	10.41	11.39
13.5	11.92	10.93	10.80	10.89	11.28	10.77	10.50	10.52	11.43
14.5	11.89	10.76	10.83	11.04	11.29	10.89	10.40	10.47	11.53
15.5	11.91	10.91	10.77	10.91	11.35	10.80	10.74	10.67	11.49
16.5	11.73	10.72	10.75	10.88	11.18	10.78	10.25	10.54	11.35
17.5	11.64	10.61	10.54	10.66	10.98	10.63	10.32	10.36	11.24
18.5	11.00	10.34	10.17	10.34	10.69	10.15	9.88	9.93	10.85
19.5	10.62	9.75	9.60	9.95	10.27	9.85	9.32	9.54	10.52
20.5	10.08	9.38	9.15	9.56	9.87	9.40	9.13	9.06	9.72
21.5	9.48	8.81	8.79	8.92	9.35	8.81	8.67	8.80	9.31
22.5	8.93	8.34	8.18	8.47	8.76	8.29	7.87	8.10	8.78
23.5	8.60	8.28	8.56	9.22	9.79	8.98	8.15	8.06	8.32

Plate-by-Plate Peak Fission Density

- Peak Fission Density ($\times 10^{20}$ fissions/cm^3)

Peak Fission Density (1E20 fissions/cc)		
Plate #	MURR DDE	MURR (Target)
1	38.57	33.72
2	34.53	27.86
3	31.24	22.5
4	28.64	18.49
5	27.45	16.17
6	26.77	14.76
7	26.30	13.54
8	25.89	12.75
9	25.64	12.16
10	25.32	11.71
11	25.18	11.43
12	24.99	11.26
13	24.81	11.33
14	24.88	11.35
15	24.83	11.42
16	24.87	11.6
17	24.96	11.98
18	25.15	12.55
19	25.50	13.53
20	26.16	14.83
21	27.21	17.01
22	29.14	20.66
23	33.30	25.89



Courtesy of Hikaru Hiruta (INL)

Radial EOL Fission Density Distribution of Limiting Plates

Courtesy of Hikaru Hiruta (INL)

- MURR Fission Density ($\times 10^{20}$ fissions/cm^3)

Distance from the top of fuel (inches)	Plate 1								
	1	2	3	4	5	6	7	8	9
0.5	16.70	16.30	15.90	16.30	15.00	16.20	16.20	16.20	17.00
1.5	17.30	16.60	16.40	16.20	15.60	16.50	16.20	16.50	17.00
2.5	19.20	18.40	18.40	18.60	17.70	18.50	18.40	18.50	19.20
3.5	22.00	21.40	21.40	21.30	20.40	21.30	21.40	21.60	22.20
4.5	24.10	23.60	23.30	23.10	22.30	23.30	23.40	23.50	24.30
5.5	26.40	25.60	25.50	25.50	24.00	25.50	25.20	25.60	26.50
6.5	27.80	26.40	26.30	26.40	25.10	26.70	26.50	26.80	27.40
7.5	28.90	28.00	27.70	27.90	26.20	27.50	27.70	28.20	28.70
8.5	30.00	29.10	28.70	28.60	27.70	29.00	28.60	29.10	29.50
9.5	31.70	30.70	30.20	30.20	29.00	30.50	30.40	30.70	31.60
10.5	32.40	31.60	31.10	31.20	30.00	31.40	31.00	31.40	32.30
11.5	33.40	32.70	32.00	32.20	30.50	32.00	31.70	32.60	33.20
12.5	33.70	32.60	32.10	32.30	30.50	32.50	32.40	32.50	33.50
13.5	33.30	32.00	31.70	31.80	30.90	32.30	31.90	32.50	33.30
14.5	32.60	31.90	31.30	31.40	30.00	31.80	31.50	32.00	32.50
15.5	30.90	30.30	29.90	30.30	28.80	30.30	29.50	30.30	31.20
16.5	29.90	28.80	28.30	28.70	27.70	29.00	28.60	29.00	29.80
17.5	27.60	27.00	26.40	26.80	25.60	26.80	26.90	26.90	27.60
18.5	26.20	25.30	25.00	25.10	23.80	25.10	25.10	25.40	26.40
19.5	24.30	23.50	23.10	23.40	22.40	23.50	23.40	23.50	24.30
20.5	22.90	22.30	21.80	22.10	21.10	21.80	21.80	22.40	22.80
21.5	20.70	20.30	19.90	19.80	19.00	20.20	19.90	20.30	20.80
22.5	19.30	18.70	18.30	18.60	17.60	18.50	18.70	18.70	19.20
23.5	20.20	19.30	19.20	19.30	18.40	19.00	19.20	19.30	20.10

Distance from the top of fuel (inches)	Plate 2								
	1	2	3	4	5	6	7	8	9
0.5	14.00	12.50	12.20	12.40	11.90	12.40	12.50	12.80	13.80
1.5	13.60	12.50	12.10	11.80	11.40	12.00	12.00	12.40	13.60
2.5	15.10	14.20	13.70	13.80	13.00	13.80	13.60	14.30	15.20
3.5	17.70	16.50	16.10	16.00	15.50	15.90	16.20	16.50	17.70
4.5	19.60	18.20	17.70	17.70	17.00	17.70	17.80	18.10	19.30
5.5	21.40	19.90	19.30	19.50	18.60	19.40	19.20	20.00	21.60
6.5	22.70	20.90	20.40	20.60	19.50	20.60	20.60	21.00	22.80
7.5	24.00	22.10	21.50	21.60	20.60	21.50	21.50	22.10	23.90
8.5	24.60	23.20	22.60	22.50	21.50	22.50	22.50	23.10	25.10
9.5	26.60	24.50	23.70	23.60	22.60	23.70	24.00	24.20	26.00
10.5	26.70	25.20	24.20	24.30	23.20	24.50	24.60	25.30	27.30
11.5	27.90	25.70	25.10	25.00	23.70	25.20	25.00	25.60	27.60
12.5	27.70	25.70	25.10	25.10	24.10	25.20	25.20	25.90	27.70
13.5	27.50	25.80	25.10	24.90	23.60	24.80	24.90	25.40	27.60
14.5	27.10	25.00	24.40	24.10	23.20	24.40	24.40	25.20	27.00
15.5	25.60	24.10	23.30	23.40	22.20	23.30	23.40	24.00	25.60
16.5	24.70	22.90	22.00	22.10	21.20	22.10	22.30	23.00	24.80
17.5	22.80	21.40	20.70	20.50	19.70	20.70	20.70	21.30	22.80
18.5	21.70	20.20	19.50	19.60	18.30	19.40	19.40	19.90	21.70
19.5	20.00	18.70	18.10	17.90	17.10	18.00	18.20	18.60	19.70
20.5	18.50	17.40	16.80	16.60	15.90	16.90	16.60	17.50	18.60
21.5	16.90	15.50	15.10	15.10	14.40	15.20	15.30	15.70	17.00
22.5	15.20	14.10	13.70	13.80	13.10	14.00	13.90	14.40	15.60
23.5	16.70	15.20	14.90	14.80	14.20	14.70	14.80	15.30	16.80

Distance from the top of fuel (inches)	Plate 22								
	1	2	3	4	5	6	7	8	9
0.5	5.31	4.81	4.59	4.62	4.70	4.62	4.54	4.76	5.37
1.5	6.97	6.23	6.12	5.94	5.83	5.90	5.88	6.11	7.08
2.5	10.40	9.00	8.78	8.46	8.26	8.61	8.73	9.31	10.30
3.5	12.70	11.20	10.80	10.50	10.20	10.50	10.80	11.30	12.80
4.5	14.50	12.70	12.10	11.80	11.50	11.90	12.20	12.80	14.30
5.5	16.30	14.20	13.60	13.20	12.70	13.20	13.60	14.20	16.10
6.5	17.40	15.20	14.50	14.10	13.70	14.20	14.80	15.20	17.60
7.5	18.40	16.20	15.50	15.10	14.60	15.10	15.40	16.40	18.50
8.5	19.10	17.10	16.30	15.70	15.30	15.90	16.30	17.10	19.10
9.5	19.70	17.50	16.80	16.30	15.80	16.50	17.00	17.60	20.10
10.5	20.20	18.00	17.30	16.70	16.20	16.80	17.00	17.80	20.10
11.5	20.40	18.30	17.50	17.00	16.40	16.90	17.30	18.00	20.70
12.5	20.20	17.90	17.50	16.90	16.40	16.90	17.40	18.00	20.40
13.5	20.30	18.10	17.10	16.80	16.30	16.80	17.20	17.90	20.40
14.5	20.00	17.40	17.00	16.40	15.90	16.50	17.10	17.70	20.10
15.5	19.60	17.30	16.10	16.10	15.50	15.80	16.30	17.20	19.40
16.5	18.60	16.40	15.80	15.40	14.90	15.30	15.80	16.50	18.70
17.5	17.80	15.70	15.10	14.50	14.10	14.50	14.90	15.50	17.80
18.5	16.90	14.60	14.10	13.80	13.40	13.60	14.10	14.70	16.70
19.5	15.60	13.80	13.00	12.70	12.40	12.60	13.00	13.60	15.50
20.5	14.10	12.50	11.90	11.70	11.30	11.60	11.80	12.50	14.10
21.5	12.40	11.20	10.60	10.40	10.10	10.30	10.70	11.30	12.50
22.5	11.50	10.00	9.57	9.24	8.90	9.20	9.43	9.73	11.50
23.5	12.40	10.60	10.20	9.93	9.58	10.00	10.20	10.50	12.20

Distance from the top of fuel (inches)	Plate 23								
	1	2	3	4	5	6	7	8	9
0.5	5.82	5.34	5.28	5.42	5.58	5.38	5.20	5.33	5.81
1.5	8.58	8.02	8.05	7.93	7.90	7.93	7.94	7.99	8.71
2.5	13.10	12.20	12.00	11.80	11.60	11.90	11.90	12.40	13.20
3.5	16.30	15.30	15.20	14.90	14.40	14.90	15.30	15.50	16.60
4.5	18.50	17.50	17.00	16.60	16.10	16.50	16.70	17.40	18.60
5.5	20.60	19.40	18.90	18.40	17.80	18.40	18.90	19.30	20.80
6.5	21.80	20.30	20.00	19.50	19.00	19.60	20.00	20.70	22.00
7.5	23.30	21.80	21.30	20.90	20.20	20.90	21.30	21.80	23.50
8.5	24.30	22.60	22.20	21.60	20.80	21.80	22.00	22.70	24.50
9.5	25.00	23.60	22.90	22.40	21.60	22.50	22.80	23.50	25.30
10.5	25.80	24.20	23.20	22.70	22.10	22.90	23.40	24.00	25.80
11.5	25.90	24.20	23.50	23.10	22.50	23.20	23.70	24.00	25.80
12.5	25.60	23.90	23.40	23.00	22.50	23.10	23.70	24.30	25.50
13.5	25.60	23.70	23.30	22.80	22.20	22.90	23.20	23.80	25.50
14.5	24.70	23.30	22.80	22.50	21.70	22.50	23.10	23.60	25.00
15.5	24.40	22.90	22.10	21.70	21.10	21.70	22.30	22.70	24.30
16.5	23.10	22.00	21.30	21.10	20.40	21.10	21.50	22.10	23.20
17.5	22.50	20.90	20.30	20.00	19.50	19.90	20.50	21.00	22.10
18.5	21.10	19.80	19.40	19.00	18.60	19.00	19.20	20.00	21.10
19.5	19.40	18.30	17.90	17.60	17.00	17.60	17.80	18.30	19.50
20.5	17.90	16.80	16.40	16.30	15.80	16.20	16.70	16.80	17.90
21.5	16.10	15.10	14.70	14.60	14.20	14.50	14.70	15.20	16.10
22.5	15.00	13.70	13.40	13.30	12.80	13.10	13.40	13.80	14.80
23.5	15.10	14.20	13.80	13.50	13.10	13.60	13.60	14.20	15.30

- MURR DDE Fission Density ($\times 10^{20}$ fissions/cm^3)

Distance from the top of fuel (inches)	Plate 1								
	1	2	3	4	5	6	7	8	9
0.5	15.54	15.95	16.32	16.45	16.50	16.36	16.06	15.53	14.97
1.5	14.85	14.89	14.94	14.97	14.95	14.83	14.64	14.46	14.12
2.5	15.68	15.77	15.78	15.84	15.81	15.73	15.56	15.31	15.05
3.5	16.90	16.82	17.05	17.01	17.04	16.86	16.59	16.43	16.12
4.5	18.41	18.36	18.50	18.42	18.42	18.40	18.18	17.86	17.65
5.5	21.91	21.69	21.55	21.66	21.52	21.40	21.17	21.10	21.15
6.5	28.90	27.59	27.03	26.78	26.65	26.57	26.69	26.89	27.94
7.5	32.58	31.00	30.32	29.93	29.78	29.72	29.82	30.19	31.49
8.5	34.44	32.70	31.93	31.58	31.39	31.32	31.40	31.83	33.30
9.5	35.84	33.97	33.11	32.68	32.43	32.49	32.58	33.02	34.59
10.5	36.67	34.85	34.14	33.71	33.40	33.29	33.39	33.99	35.61
11.5	37.58	35.56	34.68	34.21	34.07	34.06	34.12	34.71	36.43
12.5	38.09	36.20	35.23	34.72	34.52	34.52	34.62	35.23	37.00
13.5	38.53	36.51	35.49	35.07	34.83	34.78	34.91	35.56	37.30
14.5	38.54	36.52	35.65	35.10	34.88	34.90	35.00	35.69	37.50
15.5	38.60	36.51	35.54	35.17	34.96	34.90	35.00	35.64	37.24
16.5	38.34	36.39	35.37	34.93	34.84	34.63	34.86	35.38	37.21
17.5	37.98	35.84	34.97	34.50	34.25	34.23	34.38	35.03	36.78
18.5	37.15	35.20	34.32	33.93	33.72	33.63	33.88	34.39	35.98
19.5	36.30	34.47	33.52	33.12	32.96	32.81	33.05	33.44	35.11
20.5	35.23	33.35	32.55	32.18	31.93	31.91	32.00	32.59	34.17
21.5	34.09	32.35	31.49	31.06	30.82	30.78	30.91	31.50	32.83
22.5	32.63	30.81	30.09	29.75	29.48	29.47	29.54	30.03	31.48
23.5	31.52	30.65	30.44	30.35	30.17	30.19	29.98	29.78	30.47

Distance from the top of fuel (inches)	Plate 2								
	1	2	3	4	5	6	7	8	9
0.5	14.40	14.40	14.54	14.72	14.68	14.56	14.29	13.99	13.90
1.5	13.56	13.06	12.93	12.82	12.75	12.75	12.62	12.68	12.89
2.5	14.36	13.89	13.73	13.67	13.63	13.48	13.49	13.46	13.79
3.5	15.41	14.87	14.63	14.66	14.53	14.57	14.48	14.43	14.74
4.5	16.86	16.18	16.03	15.88	15.87	15.81	15.65	15.73	16.19
5.5	19.89	18.83	18.49	18.32	18.24	18.11	18.06	18.35	19.21
6.5	25.68	23.44	22.70	22.21	22.04	21.99	22.21	22.82	24.79
7.5	28.93	26.42	25.29	24.70	24.48	24.48	24.77	25.64	27.94
8.5	30.68	27.93	26.66	26.10	25.82	25.88	26.21	27.13	29.59
9.5	31.88	29.01	27.67	27.14	26.83	26.80	27.13	28.18	30.84
10.5	32.80	29.78	28.40	27.75	27.50	27.47	27.93	28.99	31.78
11.5	33.59	30.40	29.01	28.43	28.13	28.16	28.65	29.72	32.55
12.5	34.21	30.92	29.49	28.82	28.54	28.59	28.97	30.19	33.17
13.5	34.60	31.26	29.74	29.07	28.80	28.81	29.24	30.50	33.41
14.5	34.49	31.27	29.84	29.06	28.84	28.91	29.31	30.51	33.41
15.5	34.57	31.36	29.89	29.13	28.88	28.87	29.31	30.45	33.44
16.5	34.38	31.14	29.71	28.94	28.72	28.70	29.15	30.24	33.38
17.5	33.95	30.67	29.26	28.51	28.27	28.30	28.69	29.91	32.99
18.5	33.36	30.12	28.70	28.04	27.79	27.80	28.19	29.35	32.19
19.5	32.41	29.29	28.04	27.39	27.04	27.15	27.48	28.54	31.31
20.5	31.47	28.53	27.24	26.53	26.29	26.34	26.65	27.73	30.40
21.5	30.40	27.42	26.11	25.48	25.28	25.31	25.62	26.59	29.33
22.5	28.95	26.21	24.97	24.35	24.15	24.09	24.49	25.37	27.93
23.5	28.46	26.80	26.26	26.05	26.01	25.83	25.82	26.16	27.46

Distance from the top of fuel (inches)	Plate 22								
	1	2	3	4	5	6	7	8	9
0.5	9.61	8.99	8.97	9.03	9.10	8.89	8.70	8.81	9.26
1.5	9.08	8.30	7.98	7.71	7.64	7.60	7.73	8.05	8.79
2.5	9.76	8.91	8.57	8.26	8.18	8.16	8.33	8.59	9.40
3.5	10.57	9.61	9.22	8.98	8.87	8.84	9.04	9.33	10.24
4.5	11.60	10.52	10.11	9.82	9.71	9.69	9.92	10.21	11.19
5.5	13.95	12.33	11.68	11.12	10.90	10.98	11.44	11.92	13.44
6.5	18.16	15.40	14.09	12.93	12.43	12.71	13.78	14.90	17.51
7.5	20.66	17.31	15.83	14.37	13.78	14.15	15.50	16.86	20.08
8.5	22.38	18.73	17.15	15.64	15.01	15.40	16.71	18.22	21.74
9.5	24.11	20.40	18.85	17.44	16.89	17.15	18.40	19.86	23.35
10.5	26.35	22.99	21.64	20.95	20.83	20.64	21.18	22.38	25.61
11.5	28.01	24.61	23.43	23.03	23.21	22.72	22.96	23.89	27.20
12.5	28.83	25.34	24.15	23.79	24.00	23.50	23.64	24.67	27.95
13.5	29.13	25.66	24.45	24.07	24.30	23.75	23.95	24.97	28.28
14.5	29.16	25.56	24.47	24.12	24.36	23.79	23.90	24.97	28.27
15.5	29.11	25.66	24.50	24.14	24.33	23.77	23.97	25.01	28.31
16.5	29.02	25.53	24.33	23.93	24.14	23.67	23.81	24.87	28.22
17.5	28.65	25.12	23.94	23.56	23.80	23.27	23.44	24.42	27.71
18.5	27.79	24.51	23.36	23.01	23.27	22.68	22.80	23.74	26.85
19.5	26.87	23.66	22.69	22.36	22.58	22.03	22.15	23.06	26.04
20.5	25.96	22.85	21.79	21.52	21.72	21.16	21.16	22.13	25.07
21.5	24.81	21.78	20.75	20.49	20.74	20.20	20.23	21.12	23.98
22.5	23.48	20.58	19.75	19.51	19.78	19.20	19.13	19.93	22.62
23.5	23.13	21.36	21.34	22.33	23.26	22.01	20.73	20.79	22.28

Distance from the top of fuel (inches)	Plate 23								
	1	2	3	4	5	6	7	8	9
0.5	9.66	9.38	9.31	9.44	9.50	9.29	9.08	9.14	9.40
1.5	9.43	8.84	8.65	8.45	8.36	8.32	8.36	8.65	9.05
2.5	10.08	9.51	9.26	9.03	8.94	8.92	9.04	9.21	9.74
3.5	10.98	10.23	10.02	9.82	9.68	9.66	9.78	9.96	10.59
4.5	12.00	11.39	11.03	10.81	10.68	10.68	10.76	11.05	11.64
5.5	14.56	13.49	13.05	12.51	12.27	12.33	12.69	13.14	14.16
6.5	19.67	17.29	16.19	14.97	14.33	14.74	15.84	16.94	19.05
7.5	22.56	19.86	18.49	16.92	16.22	16.69	18.10	19.31	21.96
8.5	24.53	21.63	20.19	18.63	17.93	18.39	19.76	21.05	23.90
9.5	26.72	23.81	22.54	21.26	20.73	20.94	22.05	23.28	25.99
10.5	29.98	27.82	27.05	26.89	27.06	26.49	26.52	27.09	29.12
11.5	31.99	30.02	29.45	29.93	30.52	29.54	28.96	29.27	31.15
12.5	32.90	30.93	30.48	30.94	31.57	30.57	29.87	30.29	32.17
13.5	33.29	31.31	30.89	31.29	31.97	30.89	30.17	30.51	32.43
14.5	33.31	31.35	30.71	31.35	32.06	30.96	30.22	30.61	32.40
15.5	33.29	31.42	30.89	31.33	32.04	30.94	30.21	30.60	32.48
16.5	33.23	31.17	30.68	31.11	31.80	30.80	30.14	30.48	32.38
17.5	32.69	30.74	30.26	30.67	31.39	30.33	29.59	30.01	31.92
18.5	31.85	29.92	29.50	30.01	30.73	29.60	28.85	29.08	30.81
19.5	30.81	28.97	28.56	29.15	29.83	28.74	27.99	28.22	29.88
20.5	29.83	27.89	27.63	28.11	28.80	27.73	26.92	27.26	28.83
21.5	28.54	26.78	26.42	26.92	27.61	26.51	25.83	25.95	27.65
22.5	27.09	25.40	25.08	25.72	26.48	25.35	24.45	24.65	26.13
23.5	26.12	25.50	25.97	27.88	29.35	27.49	25.36	24.79	25.31

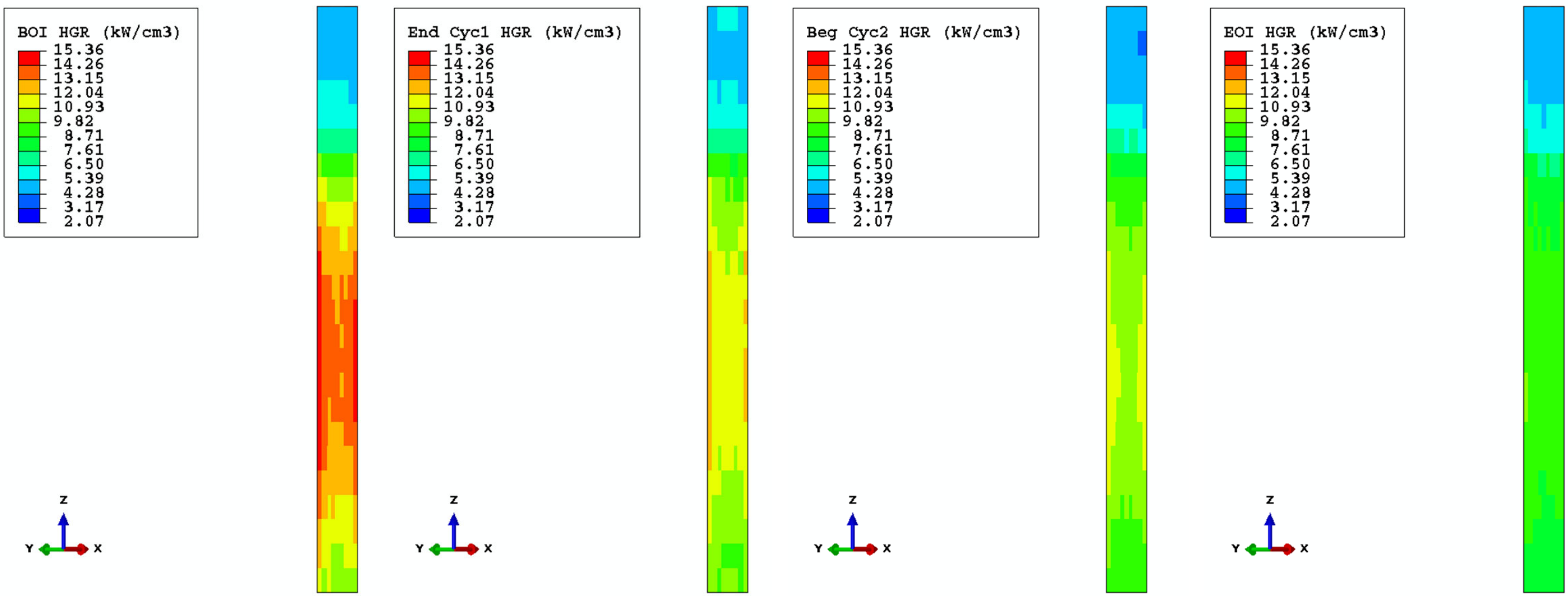
Design Inputs = a.k.a Targets

Thermal hydraulics parameters

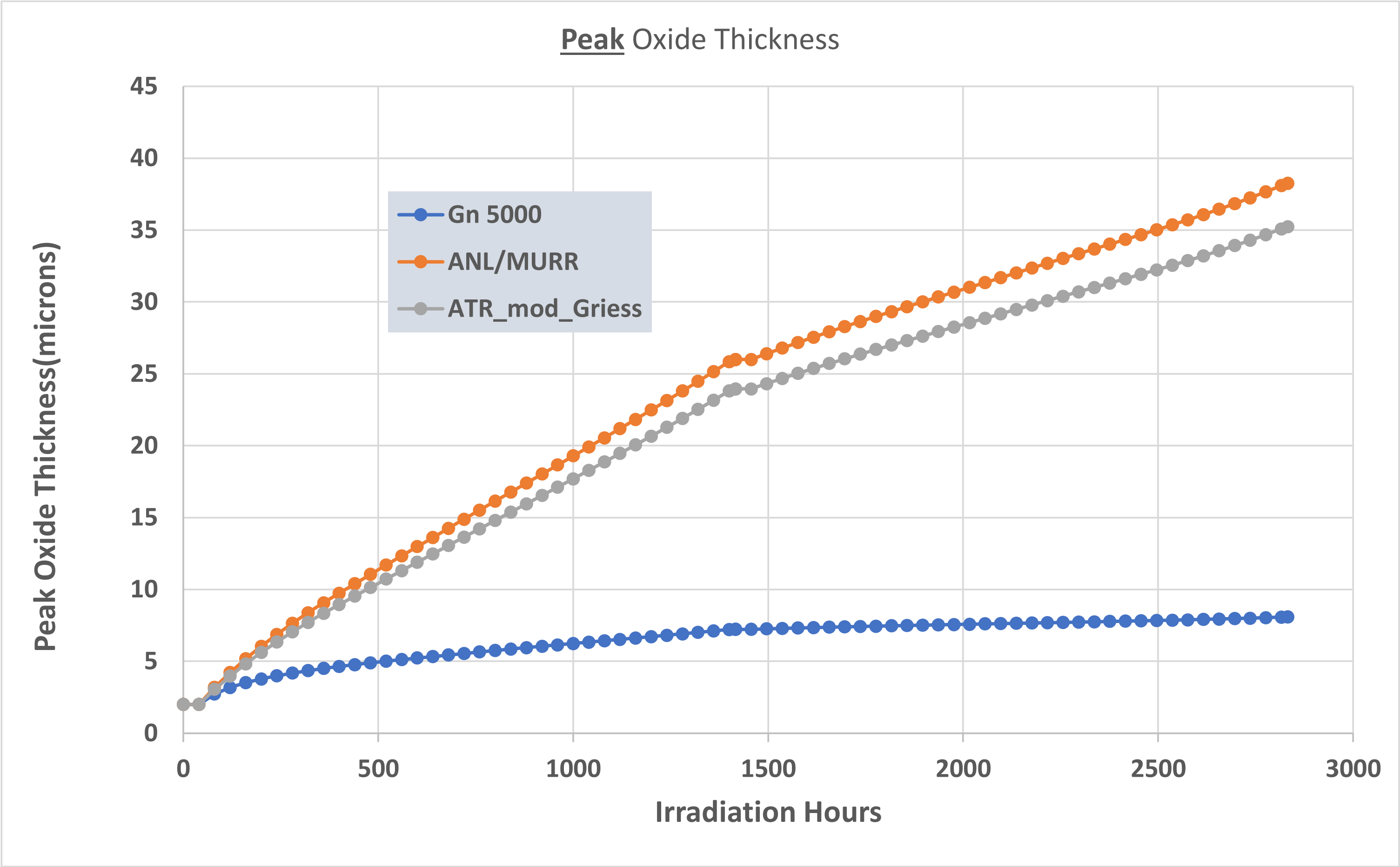
Parameter	Value
Coolant Inlet Flow Rate	0.02957 m^3/s (468.8 gpm)
Coolant Inlet Temperature	48.9° C (120° F)
Channel Averaged Inlet Flow Velocity	6.82 m/s (22.38 ft/s)
Maximum Cladding Surface Temperature	115° C (239° F)
Maximum Fuel Centerline Temperature	149° C (300° F)

Heat Generation Rates (HGRs) (kW/cm^3)

Courtesy of Grant Hawkes (INL)



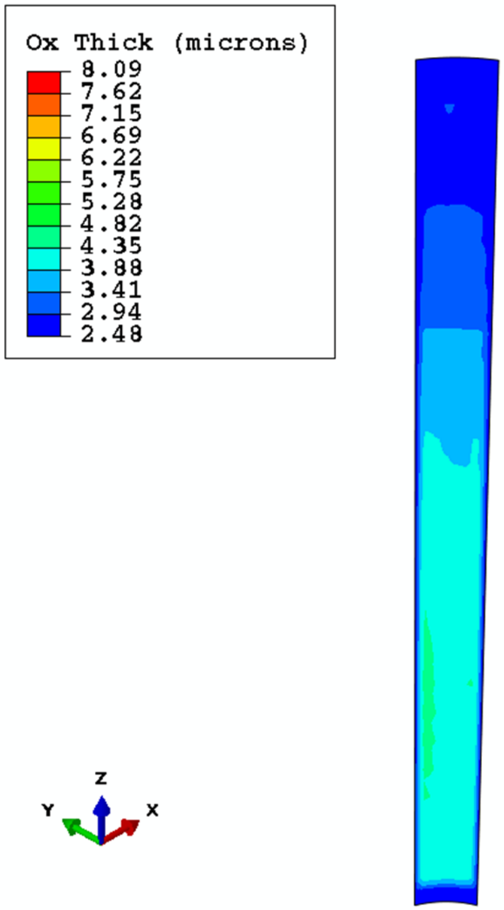
Oxide Growth



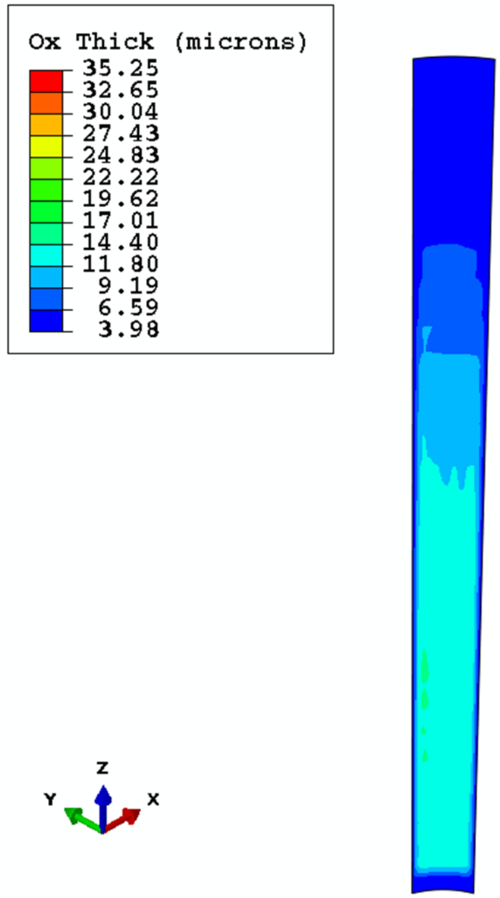
Courtesy of Grant Hawkes (INL)

Oxide Thickness at End of Irradiation

Gn 5000



ATR Griess



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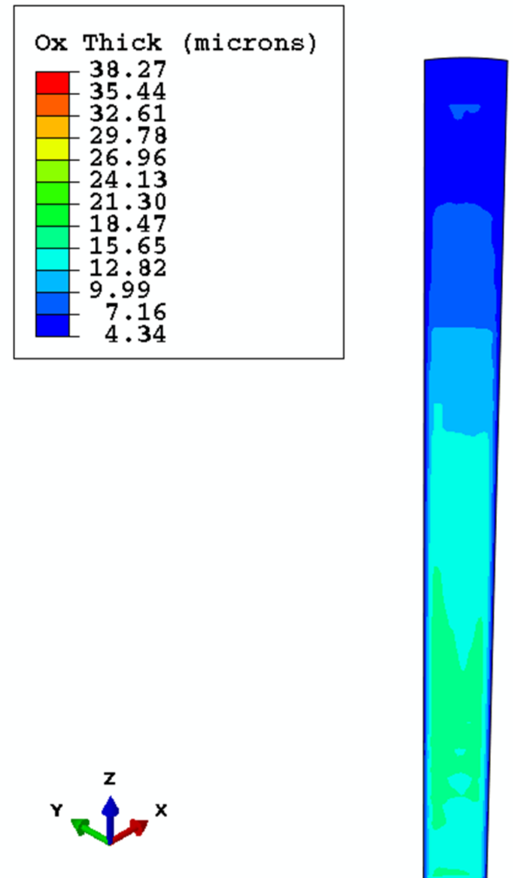
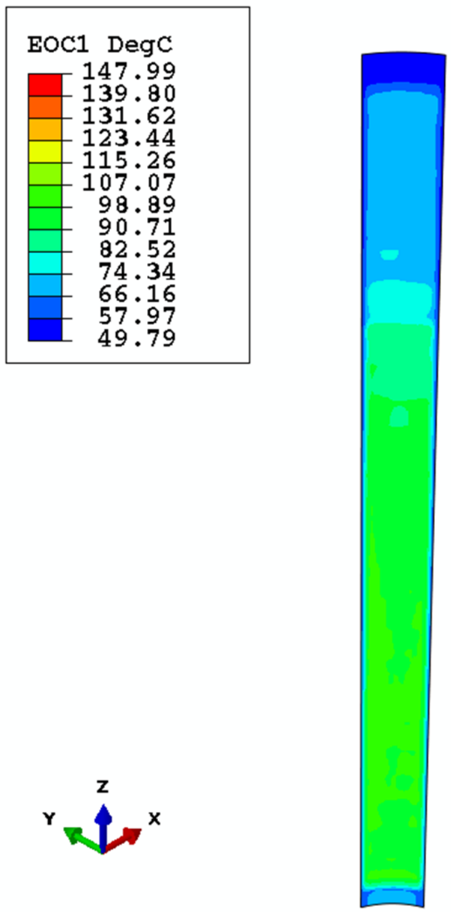


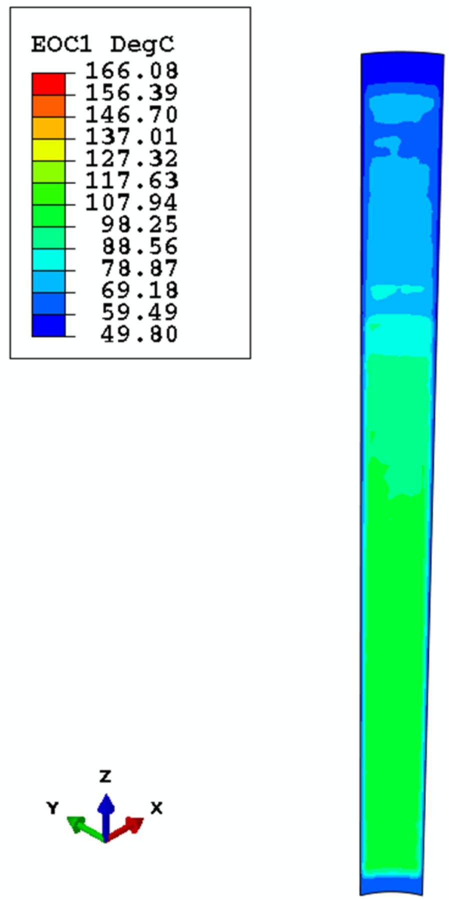
Courtesy of Grant Hawkes (INL)

Maximum Surface Temperature

Gn 5000 EOC1



ATR Griess EOC1



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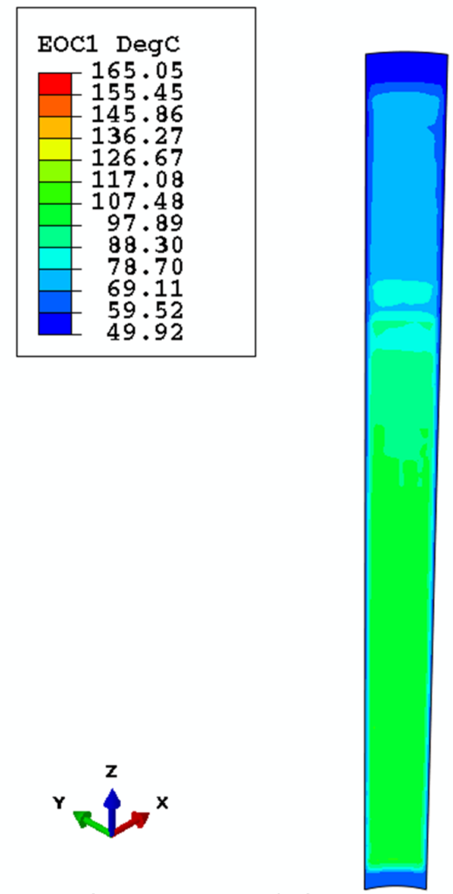
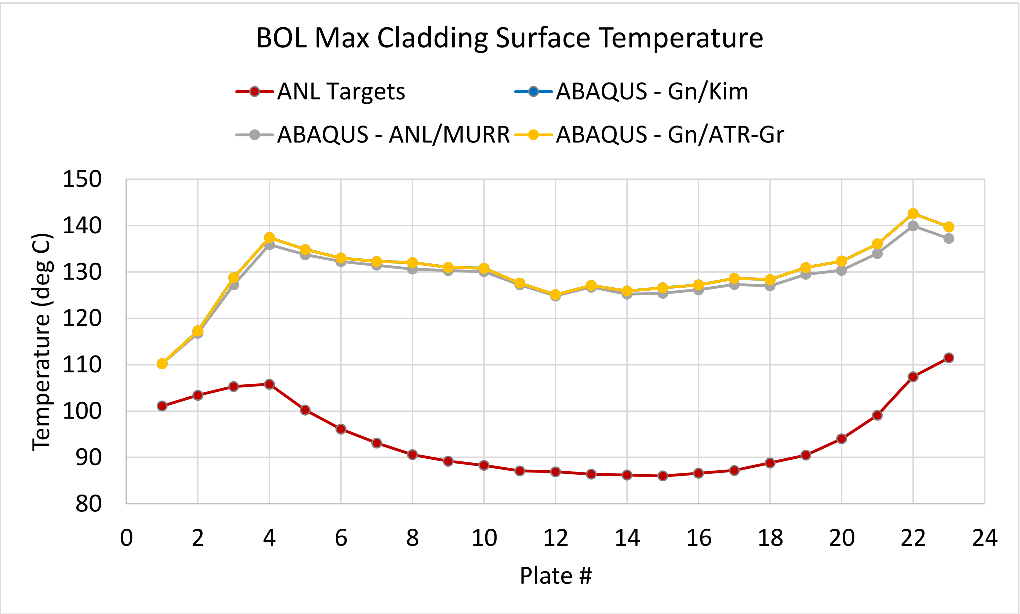
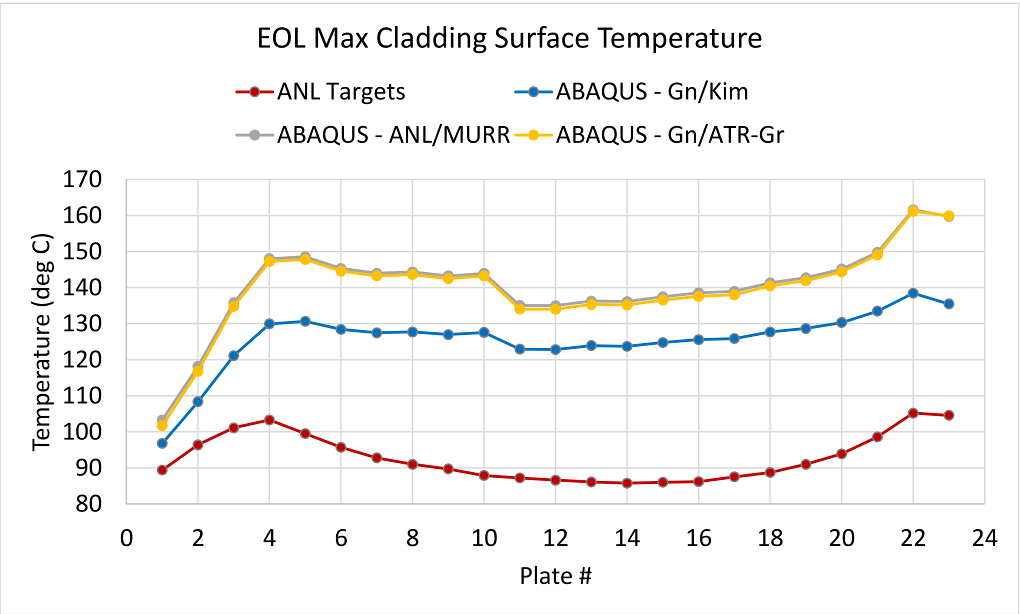


Courtesy of Grant Hawkes (INL)

Maximum Surface Temperature Varying by Plate

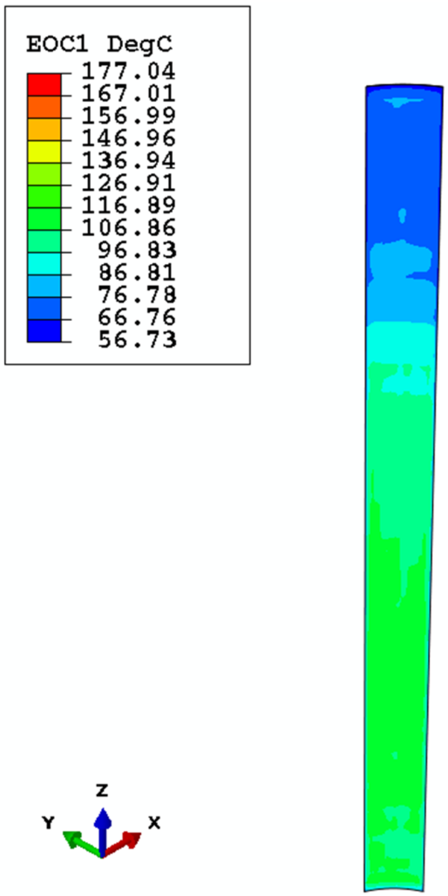
Courtesy of Grant Hawkes (INL)



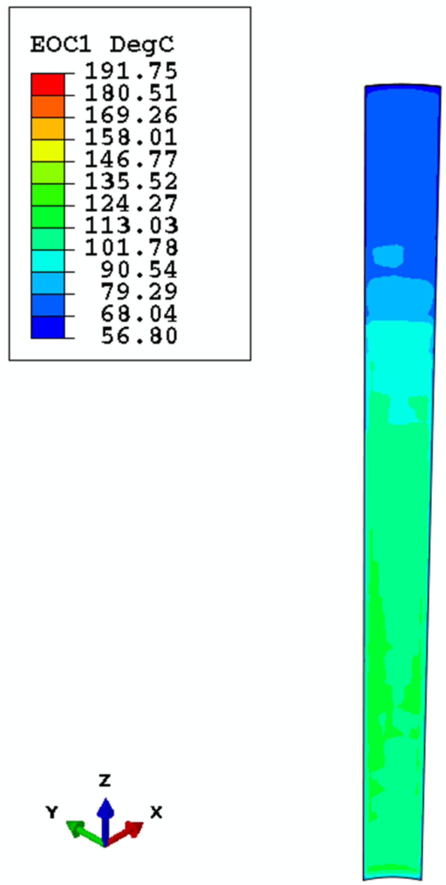


Maximum Fuel Temperature

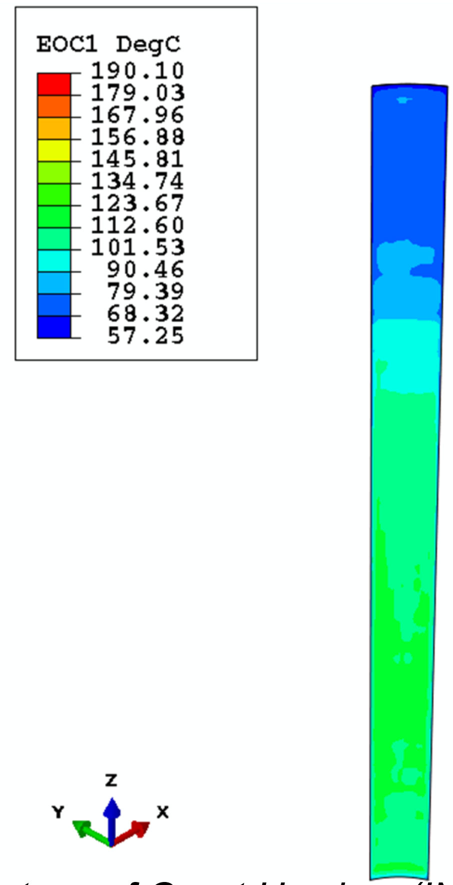
Gn 5000 EOC1



ATR Griess EOC1



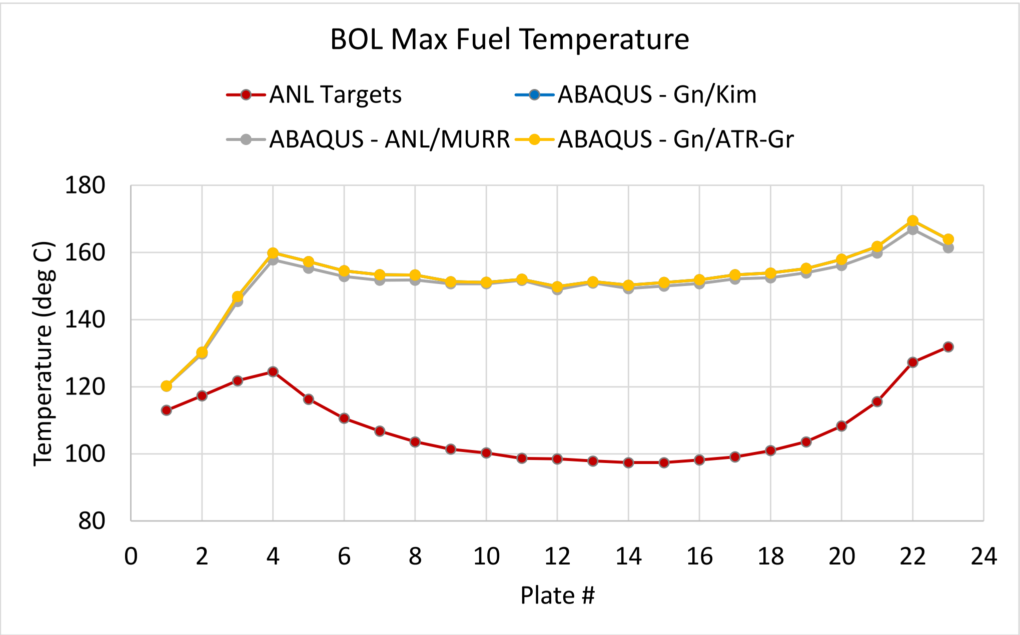
ANL-MURR EOC1

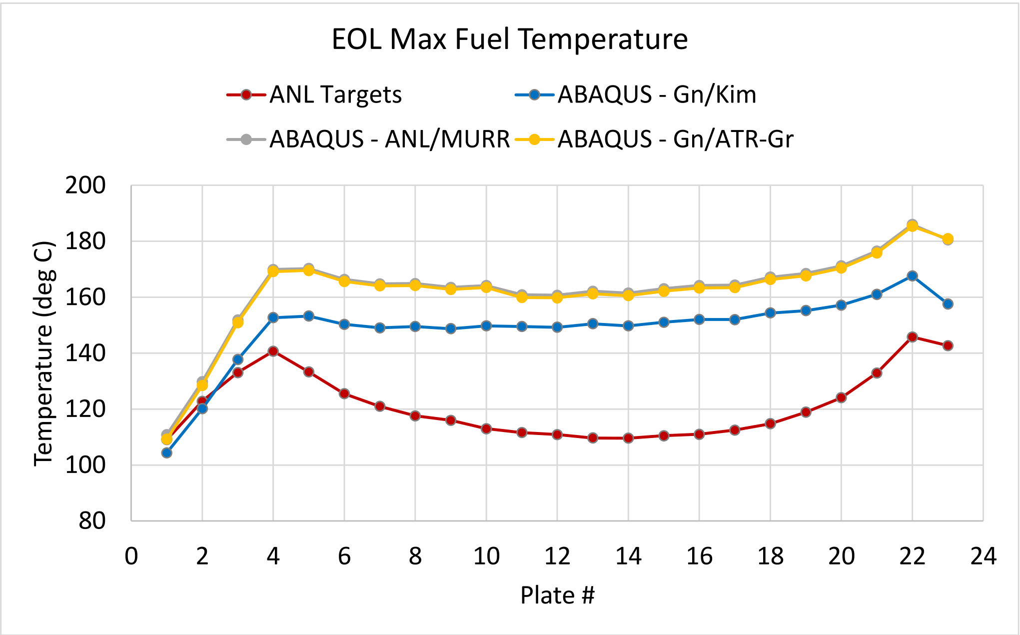


Courtesy of Grant Hawkes (INL)

Maximum Fuel Temperature Varying by Plate

Courtesy of Grant Hawkes (INL)





Additional Slides

Peak BOL Power Density

- Peak BOL Power Density (kW/cm^3) (Power Splits: 20-18-23-23-30)

	Plate 1	Plate 2	Plate 22	Plate 23
MURR DDE	15.4 (+6.68 %)	13.1 (+23.4 %)	10.0 (+35.7 %)	11.9 (+22.9 %)
Target	14.4	10.6	7.4	9.7

Percent deviation from target in ().

- Recommended Acceptance Criteria for Power Density**

Acceptance criterion	0% to + 15%
Stakeholder review and acceptance	+15% to +30%
Experiment execution exit criterion	N/A

**From FOR-512

Courtesy of Hikaru Hiruta (INL)

Peak EOL Fission Density

- Peak EOL fission density ($\times 10^{20}$ fissions/cm^3) (Power Splits: 20-18/19/21-23-23-30 in two 59-day cycles)

	Plate 1	Plate 2	Plate 22	Plate 23
1" node	38.6 (+14.5 %)	34.6 (+24.0 %)	29.2 (+38.9 %)	33.3 (+28.6 %)
2" node (FOR-512)	38.6 (+14.5 %)	34.5 (+23.7 %)	29.1 (+38.8 %)	33.3 (+28.6 %)
Target	33.7	27.9	21.0	25.9

Percent deviation from target in ().

- Recommended Acceptance Criteria for Fission Density**

Acceptance criterion	0% to + 5%
Stakeholder review and acceptance	+5% to +10%
Experiment execution exit criterion	0% to +15%

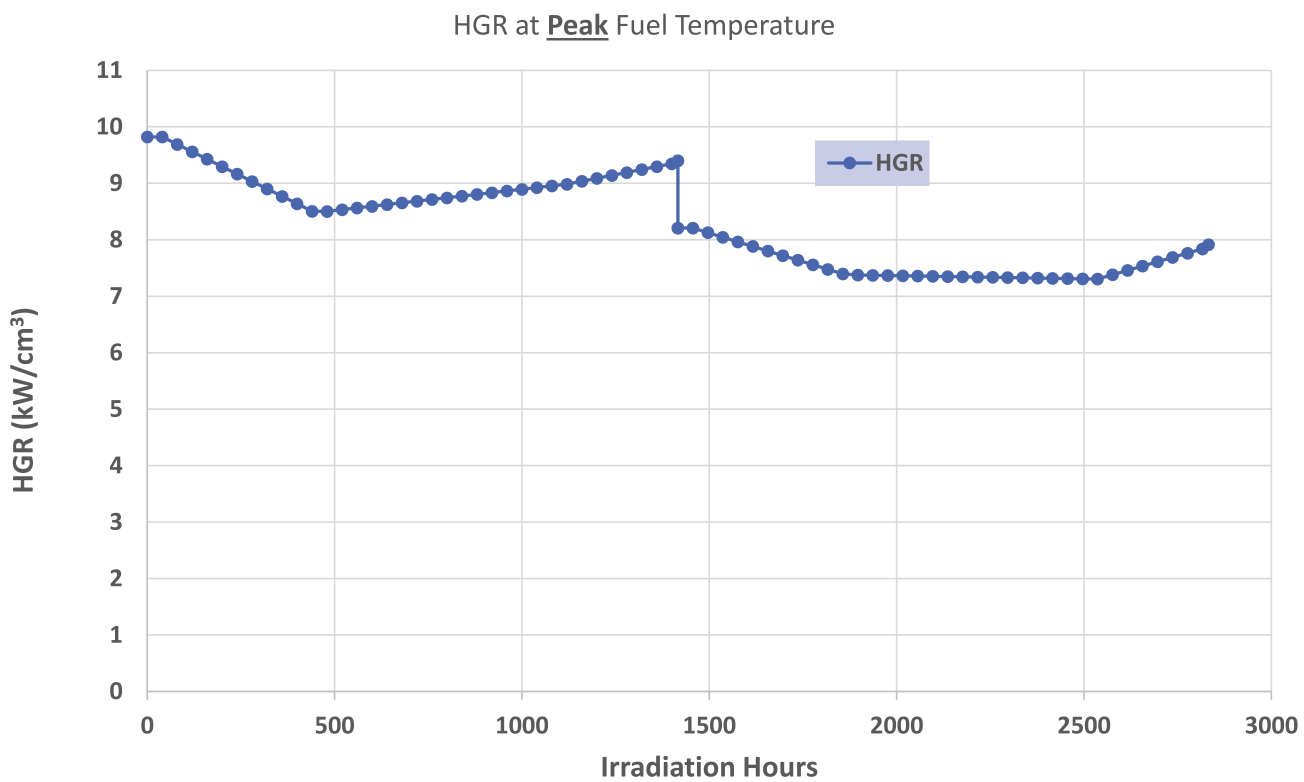
**From FOR-512

Courtesy of Hikaru Hiruta (INL)

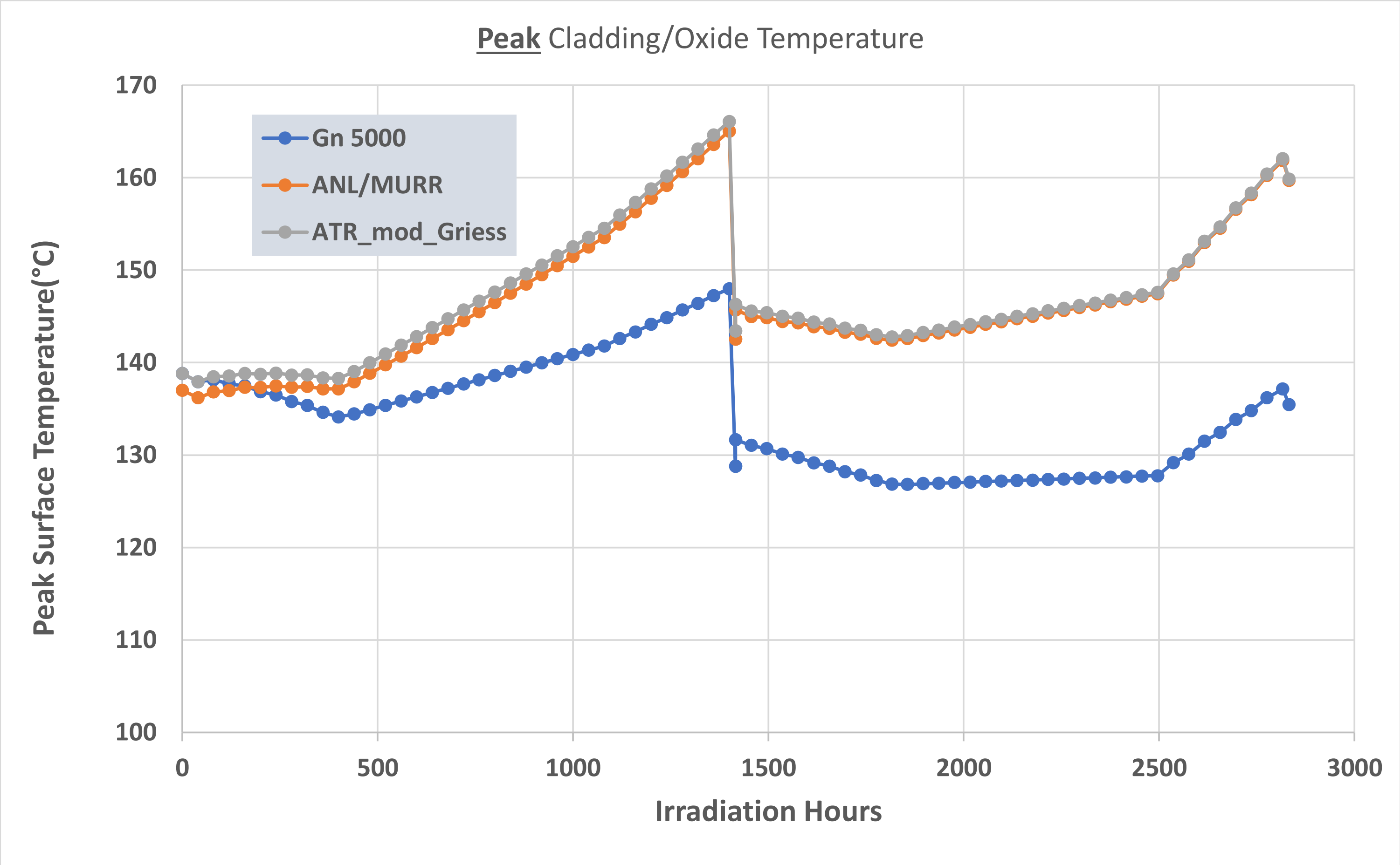
Best Estimate with Oxide Growth

- Heat Transfer Correlations (both appropriate for internal turbulent flow)
  - Gnielinski
    - $f = (0.79 \ln Re_D - 1.64)^{-2}$
    - $Nu_D = \frac{(f/8)(Re_D - 1000)Pr}{1 + 12.7(f/8)^{1/2}(Pr^{2/3} - 1)}$
  - ANL Modified Dittus-Boelter
    - $Nu_D = 0.023 Re^{0.8} Pr^{0.4} \left(\frac{\mu_{bulk}}{\mu_{wall}}\right)^{0.11}$
- Oxide Growth Correlations
  - 2019 Kim f(pH, velocity, heat flux, surface temperature, time)
  - MURR Modified Griess f(surface temperature, time)

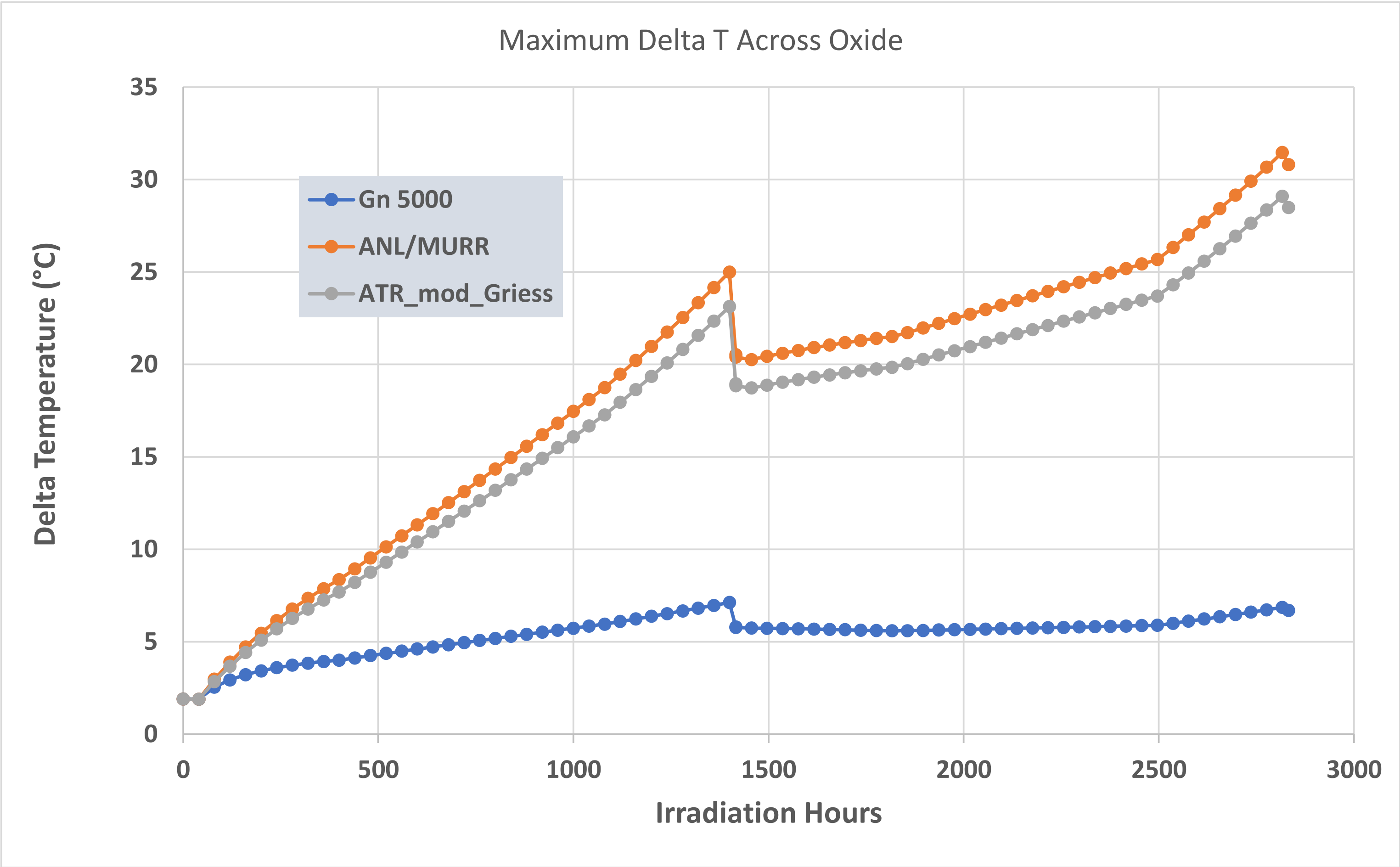
HGR Varying with Time



Maximum Surface Temperature



Maximum Delta T Across Oxide



Programmatic Limit = 119Δ°C