IER-479/547: Low-Temperature TEX

Surrogate Testing and Reflector Design

Eric Aboud, Jake Glesmann, Jesse Norris, Catherine Percher, Nick Killingsworth, Paul Yap-Chiongco

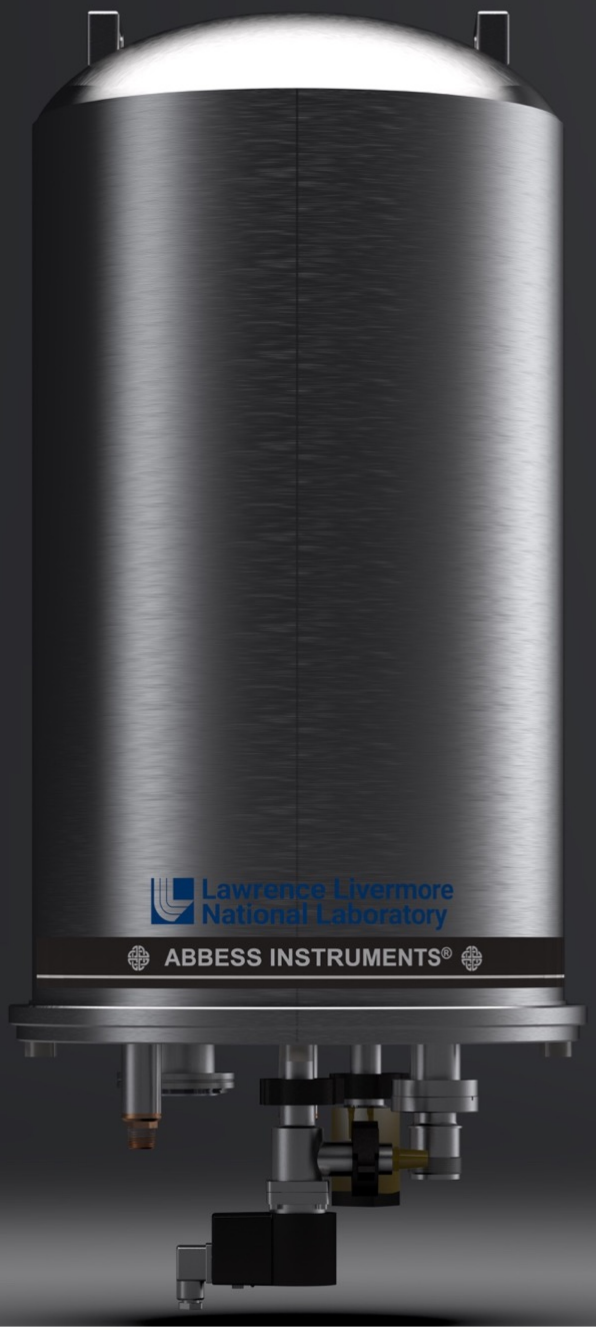
Lawrence Livermore National Laboratory

Venkata Ravindra, Steve Graham, Alfie O'Neill, Deborah Hill

National Nuclear Laboratory, United Kingdom

Technical Program Review 2024
February 21,2024

Low-Temperature
TEX



Low-Temperature Thermal Epithermal Experiments Low-Temper
Thermal Epithermal Experiments Low-Temperature Thermal Epit
Experiments Low-Temperature Thermal Epithermal Experiments
Temperature Thermal Epithermal Experiments Low-Temperature
Thermal Epithermal Experiments Low-Temperature Thermal Epit
Experiments Low-Temperature Thermal Epithermal Experiments
Temperature Thermal Epithermal Experiments Low-Temperature
Thermal Low-Temperature Thermal Epithermal Experiments Low

Experimental Configurations

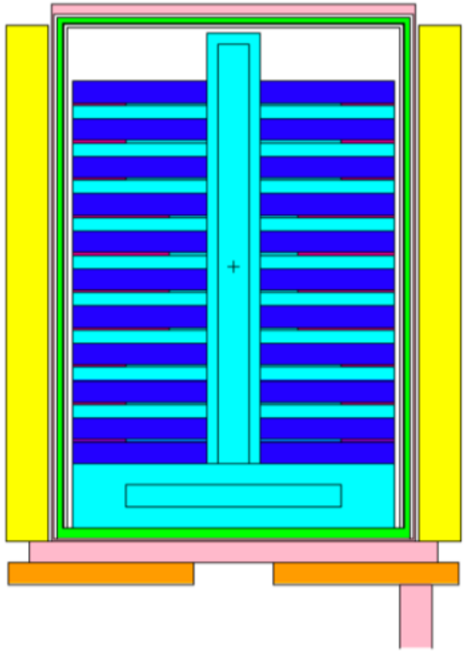
- What goes inside of the chamber?

- 6 proposed configurations spanning from predominantly thermal to fast neutron fission energies
  - 5 require the spindle heatsink
  - 1 requires the non-spindle heatsink

Case	Number HEU Plates	HEU Mass (g)	Moderator Thickness (in)	Spacer Thickness (in)	Annular Reflector Thickness (in)	Cold Critical Temp. (°C)	Multiplication Factor (k_{eff})			Fission Fractions		
							Reflected, Cold	Reflected, 20°C[a]	Handstack, 20°C[b]	Thermal (<0.625 eV)	Intermediate	Fast (>100 keV)
1	26	134,488	-	1/4	2.25	-40	1.00409	1.00360	0.88858	15%	21%	64%
2	19	93,074	1/8	3/8			1.00284	1.00313	0.87854	21%	48%	31%
3	14	68,650	1/4	1/2			1.00236	1.00329	0.88467	30%	48%	22%
4	12	50,610	1/2	1/2			1.00057	1.00629	0.88856	47%	38%	15%
5a	10	43,421	1	5/8	2.00		1.00292	1.01752	0.92108	60%	28%	12%
5b		45,290		7/8	2.50	-30[c]	1.00156	1.01265	0.89957			

(a) Represents the critical configuration reflected at 20°C using the same annular reflector, corresponding to the 80¢ excess reactivity requirement.
(b) Represents the critical configuration unreflected at 20°C using the model described in Section 3.5, corresponding to the handstack limit requirement.
(c) Case 5 is subcritical at less than -30°C, creating a more reactive configuration by increasing the HEU mass would violate the handstack limit.

Experimental Configurations

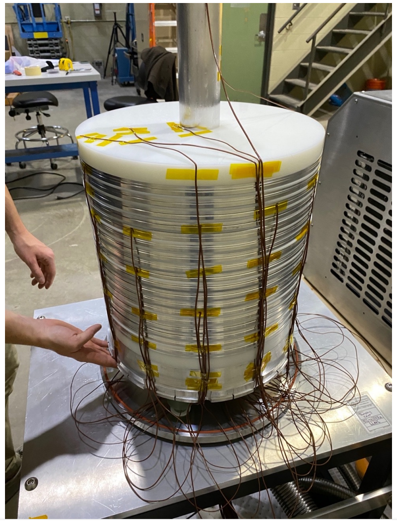


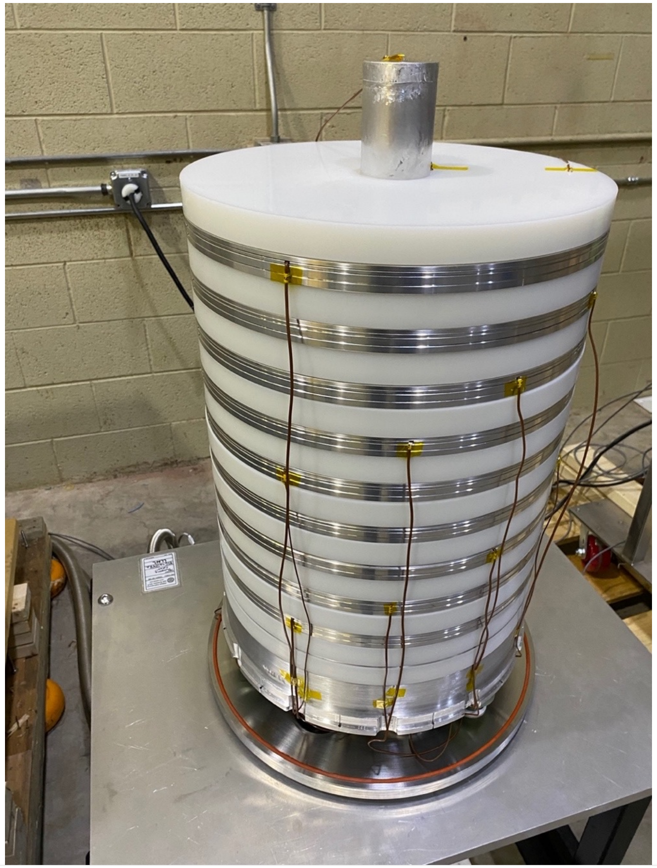
- Case 5a
  - 10 Fuel Plates
    - 6x 10” HEU
    - 4x 6” HEU
  - 5/8” Aluminum Spacers
  - 1” Poly Moderators
  - 1” Poly Top and Bottom Reflectors

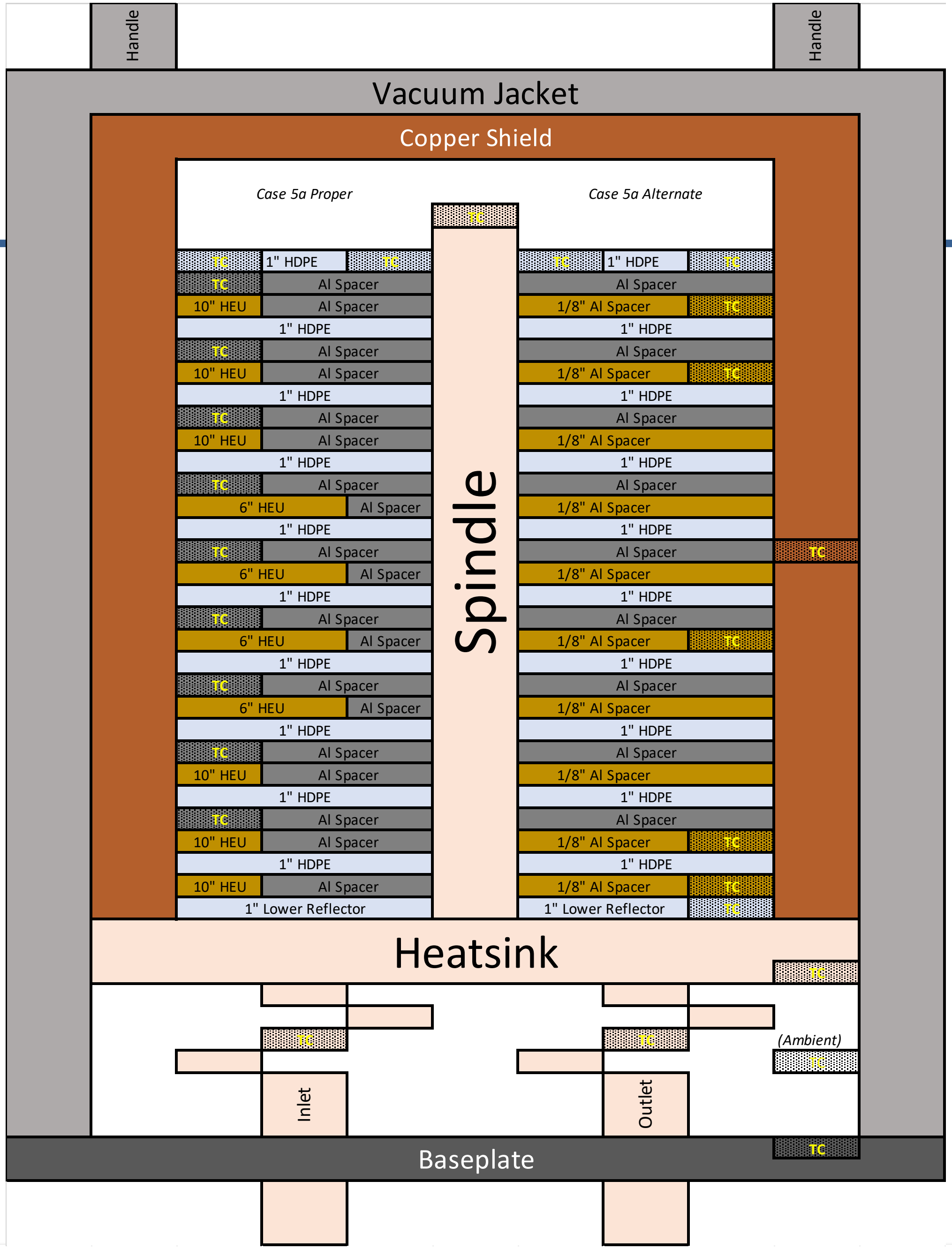
Case	Number HEU Plates	HEU Mass (g)	Moderator Thickness (in)	Spacer Thickness (in)	Annular Reflector Thickness (in)	Cold Critical Temp. (°C)	Multiplication Factor (k_{eff})			Fission Fractions		
							Reflected, Cold	Reflected, 20°C[(a)]	Handstack, 20°C[(b)]	Thermal (<0.625 eV)	Intermediate	Fast (>100 keV)
5a	10	43,421	1	5/8	2.00	-40	1.00292	1.01752	0.92108	60%	28%	12%
5b		45,290		7/8	2.50	-30[(c)]	1.00156	1.01265	0.89957			

Thermal Performance Measurements

- In order to read the temperatures in the chamber we have 38 thermocouples
- Diagnostic TC's are placed strategically to monitor the temp of the system



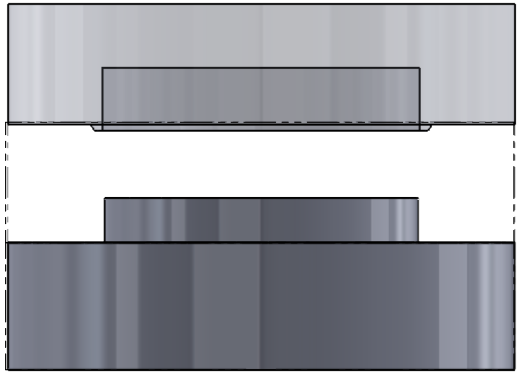


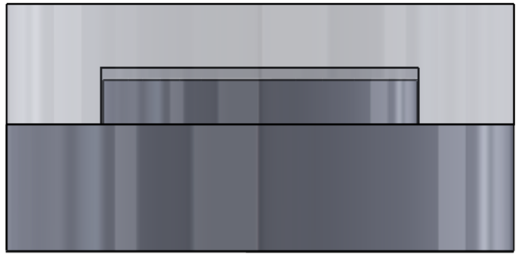


Thermal Considerations

Case 5 – Aluminum Wire

- To improve the thermal contact between the stack and the spindle, aluminum wire was pressed into the gaps
- Since testing, the spacer plates have been redesigned to allow for an aluminum gasket to fit into the gap

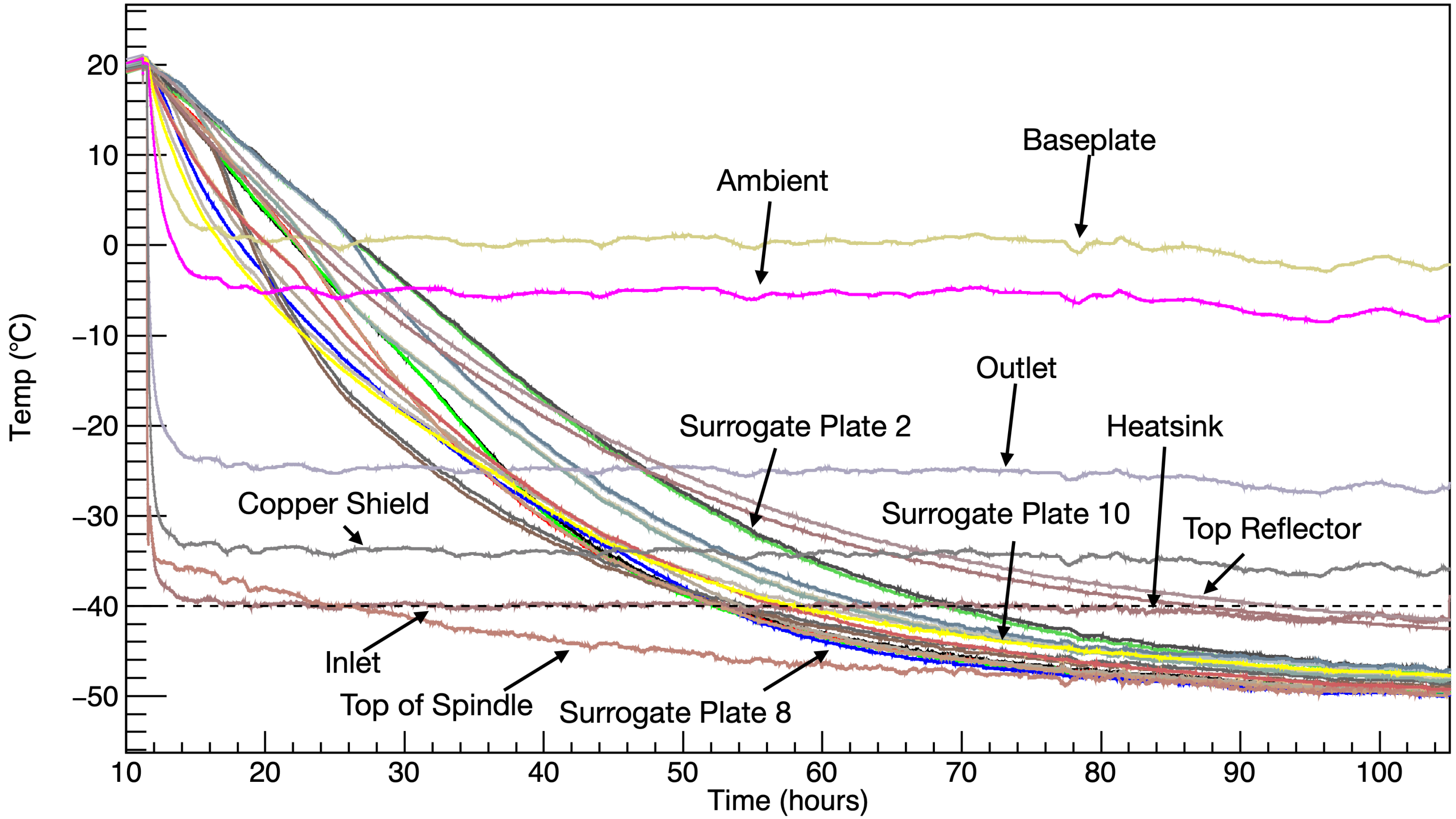




Thermal Performance

Case 5 – Aluminum Wire

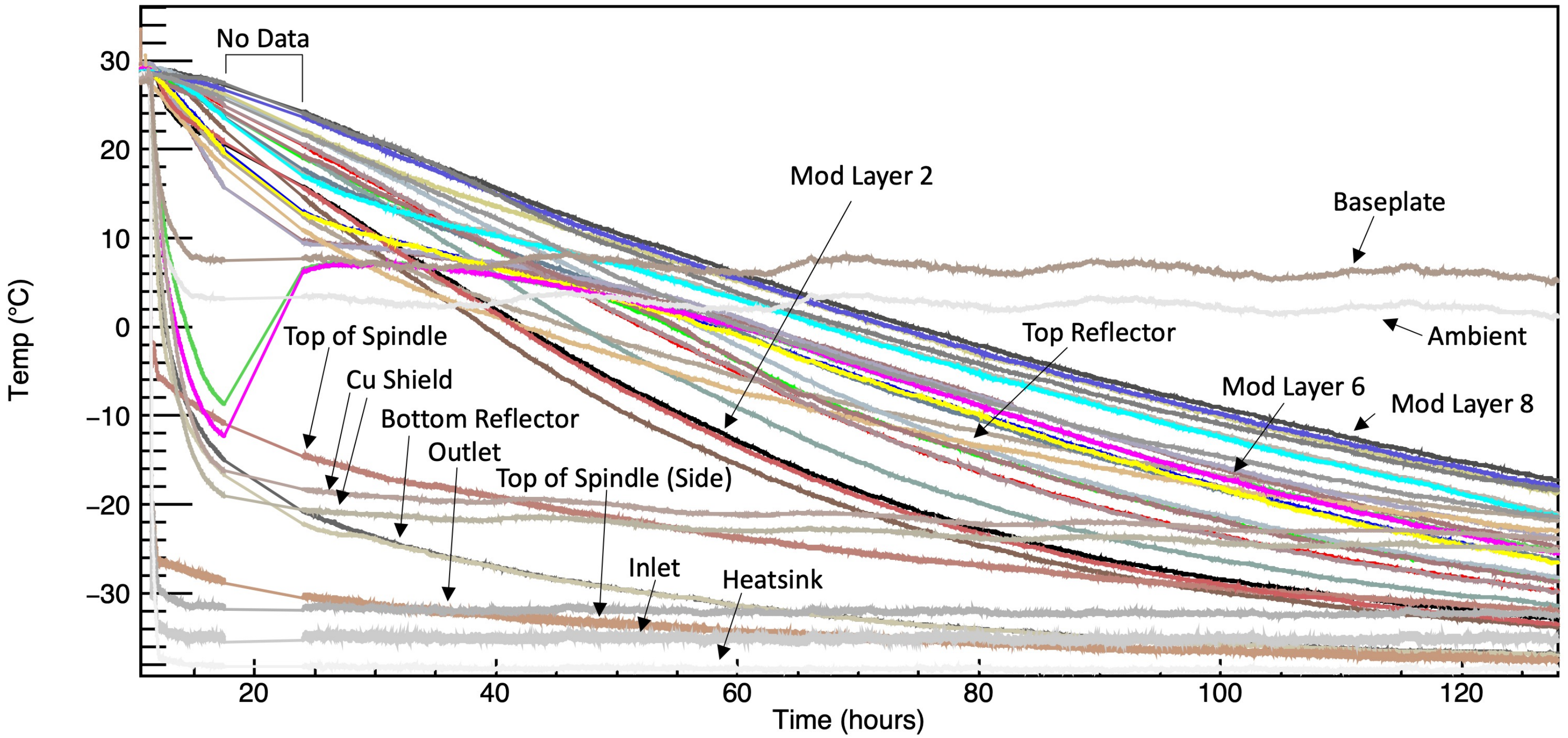
- Cooling to 40°C +/- 2.5°C within 49 hours
- Cooling overshot (issue with chiller has been fixed)



Thermal Performance

Case 5 – Copper Wire

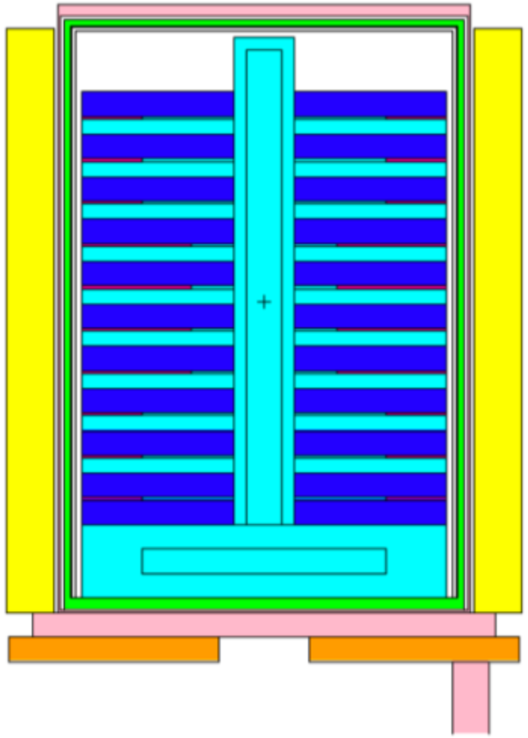
- Similarly, copper wire was tested
- Cooling to 40°C +/- 2.5°C in more than 100 hours
- Aluminum/Copper interfaces form intermetallic compounds that deteriorate conductivity [1]

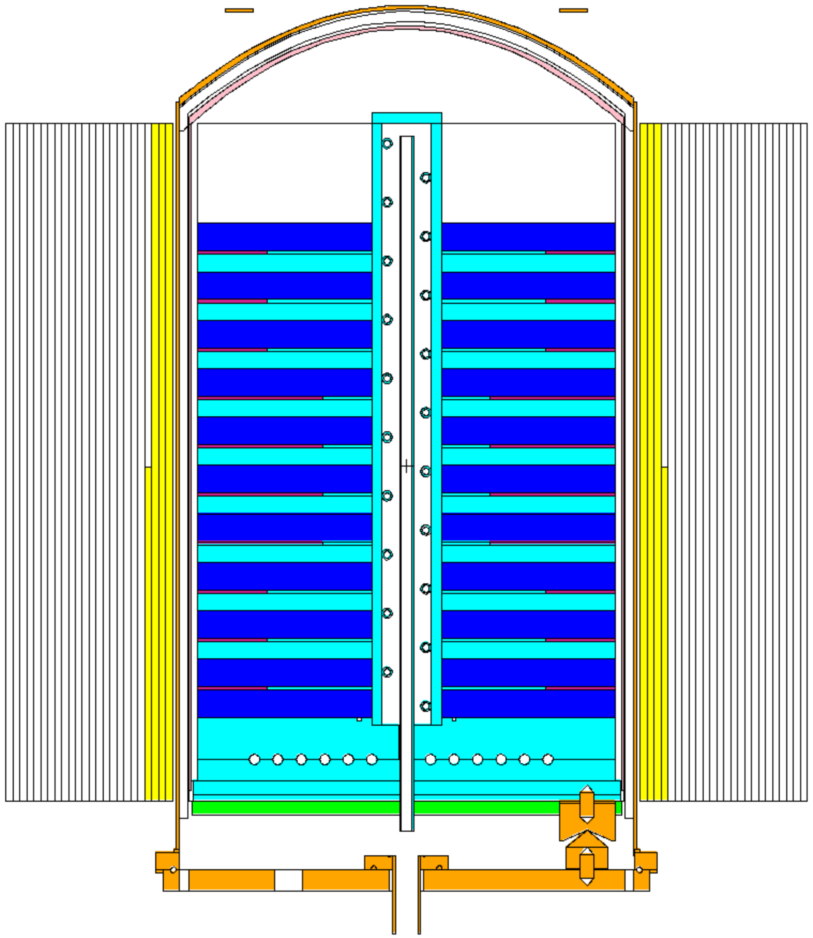


[1] Y. Wei *et al.*, “Study on the Thermal Conductivity of Cu/Al Joints with Different Interfacial Microstructures”, Advances in Materials Science and Engineering (2022)

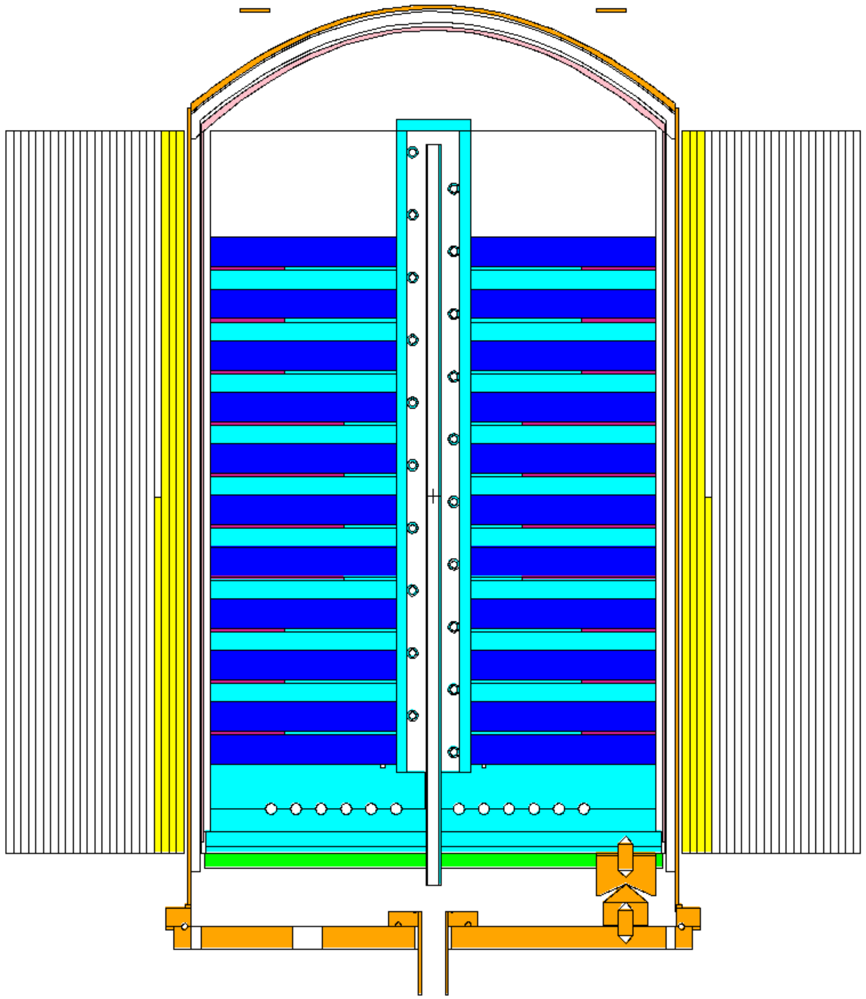
Reflector Design: The Approach

- High fidelity model
- Incrementally map k_{eff} to show reactivity worth for each segment of reflector added (both axially and annularly).

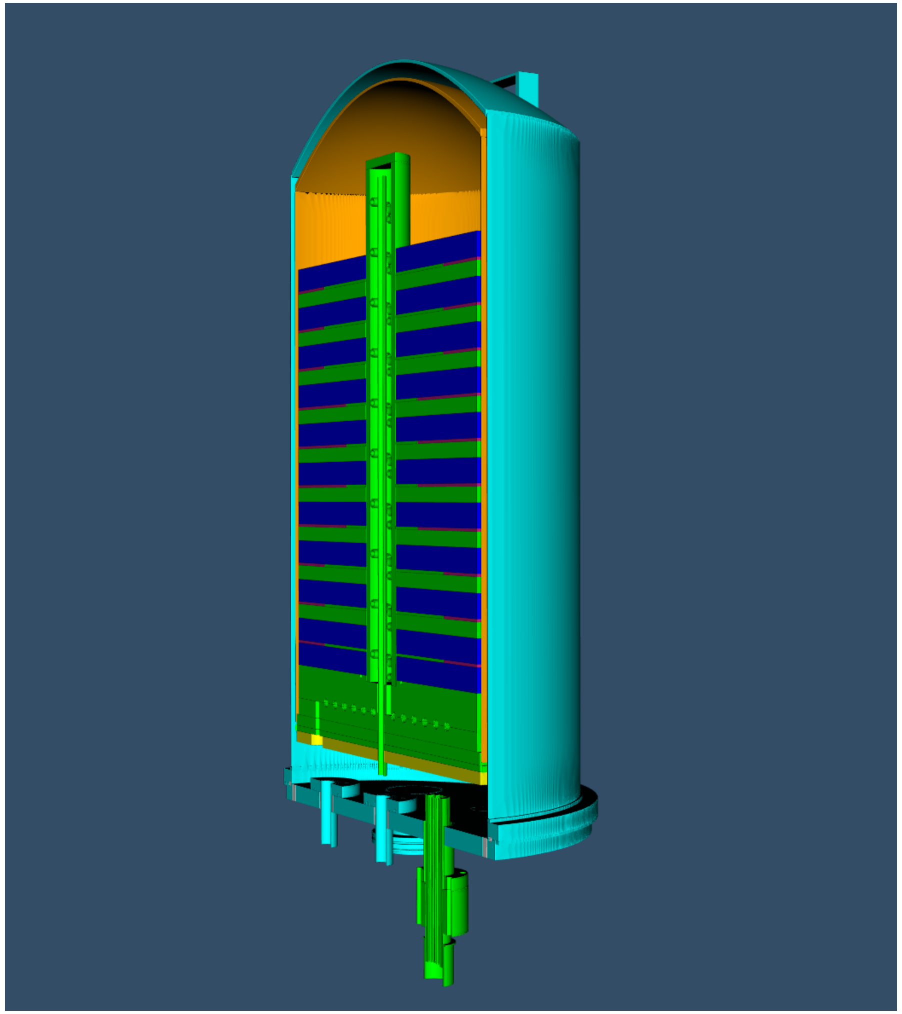




Detailed Assembly Model



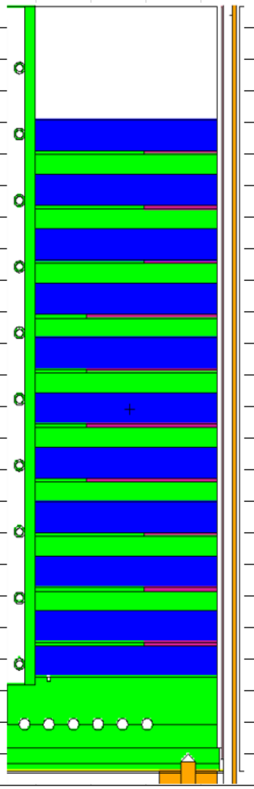
MCNP Interactive Plotter (YZ)



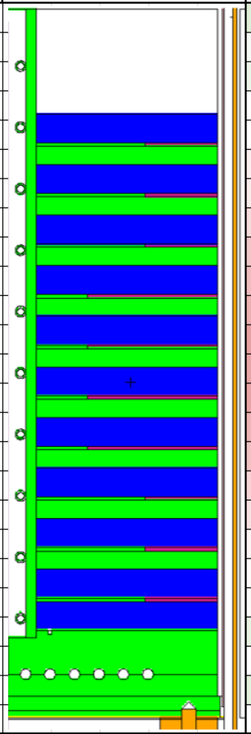
GXSview

Reflector Design: Approach

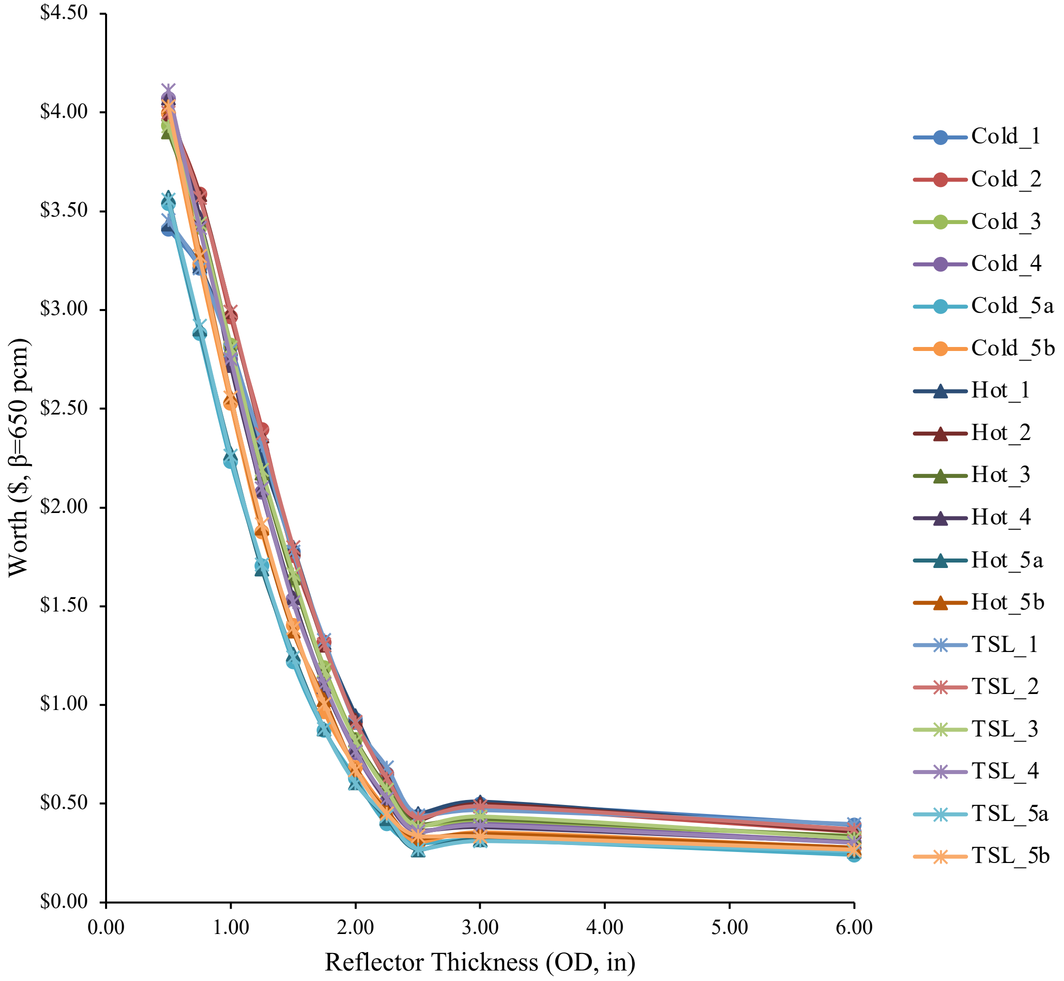
CASE 5a SUMMARY

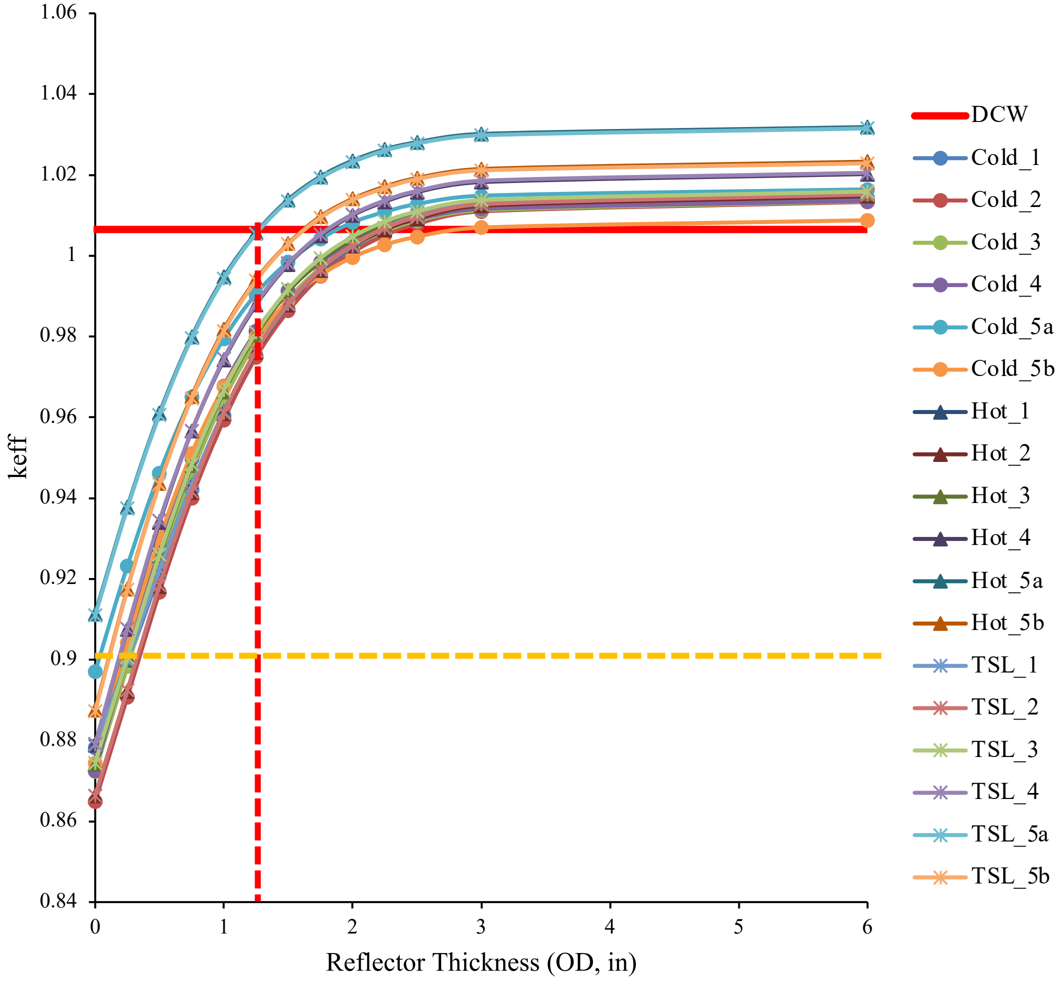
Outer Reflector Height [in]		IP YZ Cross-Section	Total Reflector Thickness (Outer Reflector Thickness) [in]											
			0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	3.00	6.00
Abs	Rel		1	2	3	4	5	6	7	8	9	10	12	24
24	21.001		0.93787	0.96108	0.97995	0.99475	1.00573	1.01390	1.01961	1.02356	1.02633	1.02807	1.03015	1.03184
23	20.001		0.93786	0.96097	0.98002	0.99475	1.00579	1.01381	1.01953	1.02347	1.02620	1.02813	1.03009	1.03184
22	19.001		0.93769	0.96093	0.98001	0.99475	1.00579	1.01391	1.01961	1.02354	1.02627	1.02819	1.03007	1.03187
21	18.001		0.93769	0.96100	0.97990	0.99475	1.00572	1.01380	1.01964	1.02358	1.02620	1.02823	1.03018	1.03171
20	17.001		0.93762	0.96082	0.97980	0.99452	1.00566	1.01388	1.01941	1.02357	1.02630	1.02821	1.03011	1.03177
19	16.001		0.93734	0.96056	0.97964	0.99438	1.00563	1.01377	1.01952	1.02347	1.02627	1.02817	1.03019	1.03180
18	15.001		0.93662	0.96006	0.97917	0.99412	1.00538	1.01353	1.01934	1.02348	1.02629	1.02802	1.03016	1.03181
17	14.001		0.93609	0.95938	0.97849	0.99367	1.00500	1.01324	1.01916	1.02337	1.02616	1.02805	1.03012	1.03182
16	13.001		0.93475	0.95823	0.97765	0.99289	1.00442	1.01287	1.01871	1.02296	1.02592	1.02790	1.03014	1.03172
15	12.001		0.93296	0.95674	0.97650	0.99194	1.00369	1.01225	1.01852	1.02282	1.02578	1.02777	1.03003	1.03181
14	11.001		0.93082	0.95482	0.97491	0.99082	1.00285	1.01163	1.01820	1.02250	1.02553	1.02762	1.03000	1.03182
13	10.001		0.92818	0.95269	0.97304	0.98941	1.00181	1.01093	1.01748	1.02207	1.02533	1.02743	1.02989	1.03179
12	9.001		0.92511	0.95019	0.97102	0.98775	1.00060	1.00996	1.01681	1.02171	1.02503	1.02736	1.02975	1.03178
11	8.001		0.92223	0.94746	0.96897	0.98611	0.99933	1.00917	1.01633	1.02140	1.02475	1.02712	1.02974	1.03178
10	7.001		0.91938	0.94513	0.96701	0.98453	0.99829	1.00838	1.01570	1.02093	1.02457	1.02686	1.02960	1.03190
9	6.001		0.91704	0.94309	0.96524	0.98342	0.99718	1.00774	1.01521	1.02052	1.02421	1.02671	1.02954	1.03179
8	5.001		0.91505	0.94110	0.96381	0.98226	0.99633	1.00713	1.01475	1.02016	1.02405	1.02652	1.02948	1.03189
7	4.001		0.91361	0.93992	0.96278	0.98124	0.99575	1.00654	1.01438	1.01998	1.02387	1.02637	1.02954	1.03185
6	3.001		0.91257	0.93898	0.96185	0.98069	0.99518	1.00628	1.01418	1.01974	1.02370	1.02637	1.02945	1.03168
5	2.001		0.91182	0.93835	0.96157	0.98025	0.99492	1.00595	1.01408	1.01961	1.02368	1.02637	1.02932	1.03184
4	1.001		0.91151	0.93799	0.96125	0.98013	0.99487	1.00599	1.01411	1.01961	1.02353	1.02633	1.02941	1.03180
3	0.001		0.91146	0.93790	0.96096	0.97992	0.99473	1.00588	1.01373	1.01961	1.02355	1.02617	1.02938	1.03173
2	-0.999		0.91142	0.93787	0.96117	0.97985	0.99480	1.00580	1.01380	1.01964	1.02345	1.02619	1.02942	1.03180
1	-1.999		0.91135	0.93766	0.96098	0.97995	0.99473	1.00577	1.01395	1.01961	1.02353	1.02632	1.02925	1.03180
0	-2.999		0.91139	0.93787	0.96108	0.97995	0.99475	1.00573	1.01390	1.01961	1.02356	1.02633	1.02931	#N/A
Total Keff			0.937867	0.961076	0.979952	0.994746	1.005725	1.013897	1.019606	1.023556	1.026331	1.028069	1.030149	1.03184
			Worth (pcm)	2320.9	1887.6	1479.4	1097.9	817.2	570.9	395	277.5	173.8	208	169.4
			Worth ($)	$3.57	$2.90	$2.28	$1.69	$1.26	$0.88	$0.61	$0.43	$0.27	$0.32	$0.26

CASE 5a SUMMARY

Outer Reflector Height [in]		IP YZ Cross-Section	Total Reflector Thickness (Outer Reflector Thickness) [in]											
			0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	3.00	6.00
Abs	Rel		1	2	3	4	5	6	7	8	9	10	12	24
24	21.001		-7.1	14.0	6.3	-12.2	6.1	-4.3	-11.8	7.8	6.4	0.1	13.9	15.3
23	20.001		8.8	-15.5	5.2	-1.4	9.1	0.3	1.7	-2.1	-8.4	4.4	11.6	15.3
22	19.001		2.4	4.3	-6.3	7.6	-13.4	-4.9	15.3	5.0	0.0	7.2	-9.7	0.8
21	18.001		15.9	13.6	10.5	19.4	14.5	7.5	-19.7	1.3	-10.4	-4.2	5.2	14.9
20	17.001		14.5	9.3	23.0	6.3	5.7	17.7	15.1	-2.0	14.8	6.7	-1.9	-22.9
19	16.001		67.6	57.1	35.8	24.4	22.3	19.4	14.1	10.4	7.9	10.9	6.4	2.5
18	15.001		73.9	72.9	56.7	48.8	44.4	16.4	12.3	13.9	1.3	2.6	-10.0	-4.9
17	14.001		121.0	115.1	83.5	72.9	51.3	36.0	32.8	18.7	18.4	3.4	11.4	4.4
16	13.001		187.5	134.6	127.3	93.5	57.9	69.6	44.8	22.8	13.7	10.7	-2.2	12.2
15	12.001		215.9	212.2	148.6	121.1	94.5	51.3	40.1	39.0	28.5	28.5	11.5	-17.6
14	11.001		251.0	206.0	183.2	137.9	114.7	73.4	54.2	34.5	23.6	18.5	10.9	8.2
13	10.001		297.3	248.3	197.8	166.6	102.0	81.8	67.1	41.9	23.1	1.9	5.5	-7.1
12	9.001		287.1	270.1	216.2	148.7	125.7	97.5	40.1	41.7	30.8	15.5	5.9	2.7
11	8.001		289.2	243.8	187.3	159.4	109.4	63.6	72.0	31.4	33.5	35.0	11.1	-7.6
10	7.001		240.2	209.9	181.2	129.8	103.2	78.3	41.4	38.7	19.5	1.8	13.9	16.1
9	6.001		200.4	187.7	150.3	116.7	73.7	61.3	54.6	24.1	22.7	13.9	-6.0	5.8
8	5.001		144.2	122.4	102.4	79.9	76.5	50.4	31.6	45.7	17.8	5.3	-1.4	-17.4
7	4.001		105.4	82.5	79.3	59.6	41.4	31.7	28.6	5.5	11.2	19.3	12.3	6.6
6	3.001		52.7	57.8	39.4	30.9	23.2	27.5	12.3	11.6	-0.8	-9.3	2.9	-0.7
5	2.001		26.3	28.1	14.0	39.7	28.5	8.2	18.3	1.8	12.4	18.8	-2.0	-8.7
4	1.001		11.5	20.5	17.4	4.2	-4.4	11.9	-24.7	7.9	0.8	3.2	3.9	13.1
3	0.001		-0.6	-8.9	10.0	-3.2	10.2	-13.5	29.1	-1.0	2.2	-15.6	1.7	-7.7
2	-0.999		17.0	10.2	3.7	14.0	6.5	6.5	-11.3	9.6	-5.0	2.7	1.8	8.5
1	-1.999		-4.5	3.7	-0.4	-12.4	6.0	4.7	9.0	0.1	-5.2	13.1	8.8	8.5
0	-2.999		-	-	-	-	-	-	-	-		-	-	-
Cumulative Worth			*2617.6*	*2299.7*	*1872.4*	*1452.2*	*1109.0*	*792.3*	*567.0*	*408.3*	*258.8*	*194.4*	*105.5*	*16.5*
Total Keff			0.87272	0.90114	0.92759	0.94997	0.96763	0.98135	0.99125	0.99846	1.00336	1.006743	1.010579	1.013687

Reflector Calculation Design





Conclusions

- Progress in surrogate testing
  - A new chiller has been fabricated and testing has resumed
  - Additional tests are being conducted, including:
    - Using formed aluminum gaskets
    - Extended testing with natural uranium
    - Testing with pseudo-spindle
    - Testing with no vacuum

- Reflector Design
  - Results for detailed model are consistent with results presented in CED-2.
  - Calculations provide flexibility in the physical design of the reflectors (e.g. reflector segment widths and heights).
  - Provided initial CAD models of reflector components.

Lawrence Livermore National Laboratory

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC