IER-297: TEX-HEU Baseline Assemblies Benchmark and Results

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Nuclear Criticality Safety Program
Technical Program Review
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Overview

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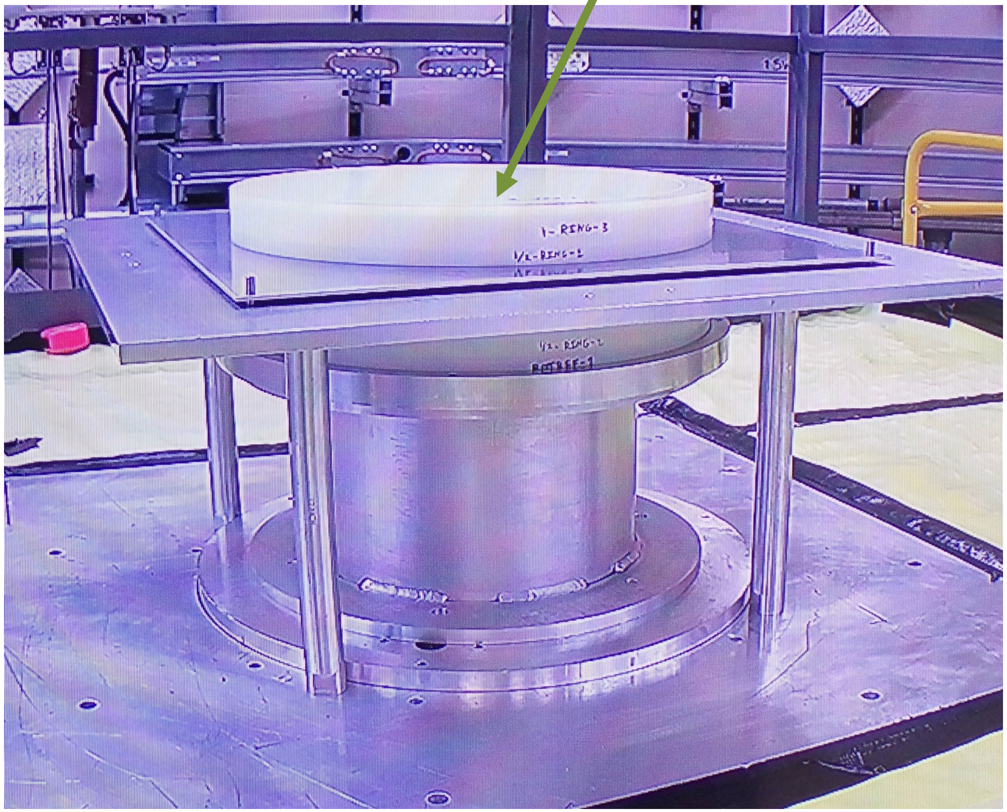
2. Experimental Configurations
3. Uncertainty and Bias
4. Benchmark Detailed and Simplified Models
5. Benchmark Results
6. Conclusion



TEX with Highly Enriched Uranium (TEX-HEU)

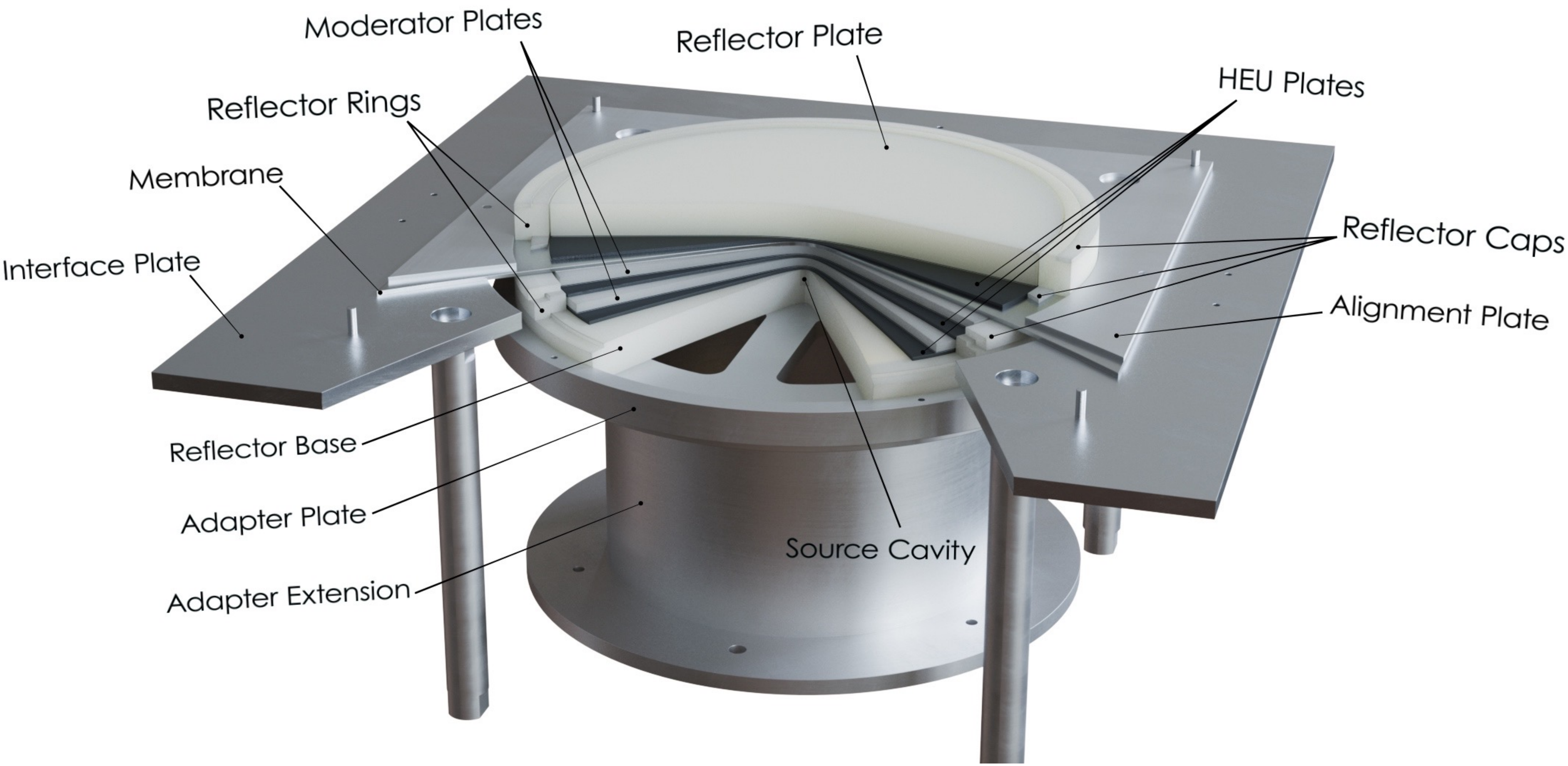
- Highly enriched (93+) uranium (HEU) fuel design with polyethylene moderator and reflector

- Varying the thickness of the polyethylene moderator plates allows the neutron spectrum to be fine-tuned to a specific energy regime
  - From fast (no polyethylene) to thermal (up to 1.5” of polyethylene)
  - Five moderator plate thicknesses: 0” (none), ⅛”, ¼”, ½”, and 1½”

- Top reflector provides the fine reactivity control
  - Reflector thickness in increments as little as 1/32”

- TEX-HEU was designed to incorporate diluent materials with the ability to focus on a specific energy regime

TEX-HEU Design

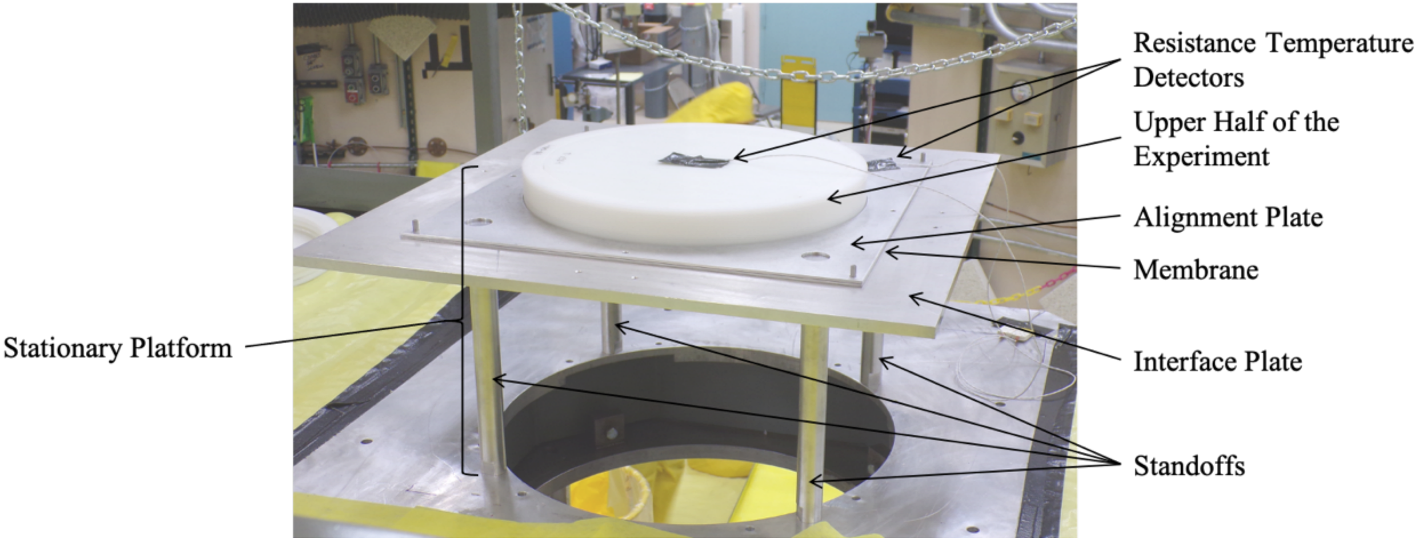


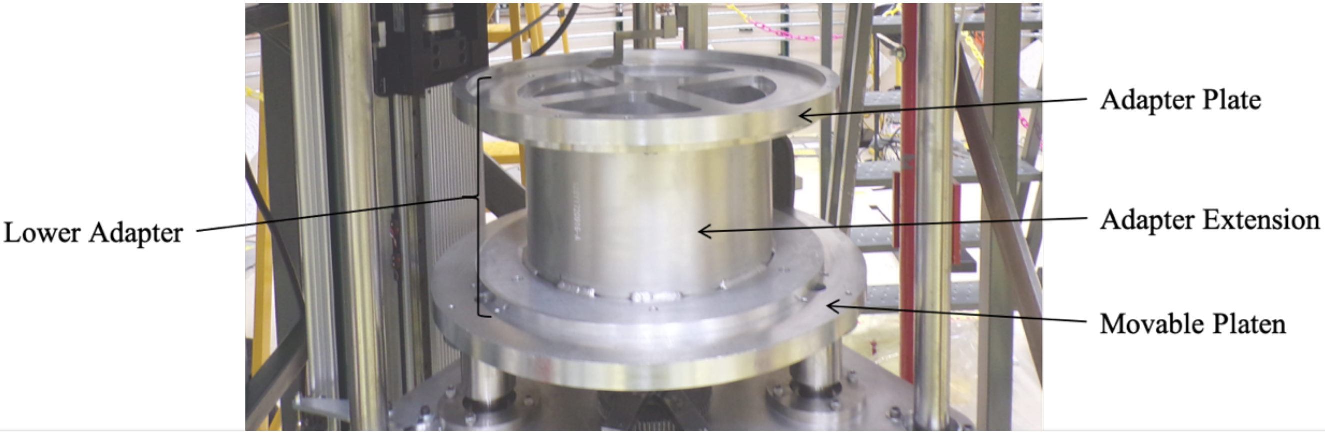
Experiment Execution

- Executed in the National Criticality Experiment Research Center of the Nevada National Security Site
- Assembled on the Comet General Purpose Critical Assembly Machine
  - Vertical lift machine allowing safe remote assembly of the critical mass
- Campaign occurred in two parts, for a total of 5 weeks
  - Halted halfway through due to the COVID-19 pandemic
  - LANL's NEN-2 Group was able to successfully stand the facility back up in May to complete the campaign

Comet General Purpose Critical Assembly Machine

Comet General Purpose Critical Assembly Machine





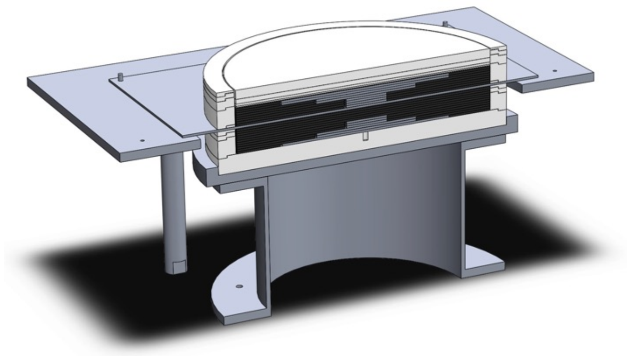
Experimental Configurations

- Five benchmark experimental configurations
- Differ based on the nominal polyethylene moderator plate thickness used to vary the fission energy regime

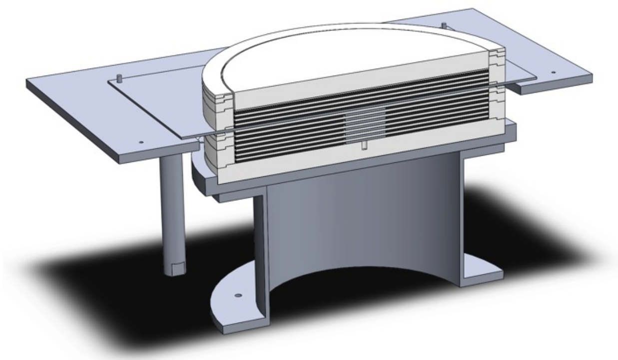
Case	Number of HEU Plates	Total HEU Mass* (g)	Nominal Moderator Thickness, in (cm)	Nominal Top Reflector Thickness, in (cm)
1	19	109,059.7 ± 13.9	-	0.96875 (2.460625)
2	11	69,986.9 ± 10.6	0.125 (0.3175)	1.0625 (2.69875)
3	8	51,007.8 ± 9.1	0.25 (0.635)	1.21875 (3.095625)
4	5	32,282.8 ± 7.2	0.5 (1.27)	1.65625 (4.206875)
5	5	29,529.4 ± 7.2	1.5 (3.81)	1.0125 (2.57175)

*Based on an evaluated uncertainty of ±3.2 grams per HEU plate.

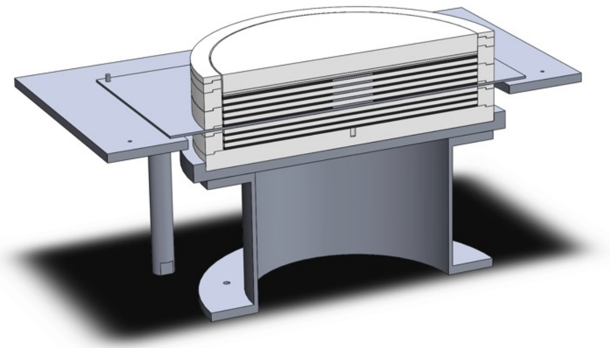
Experimental Configurations



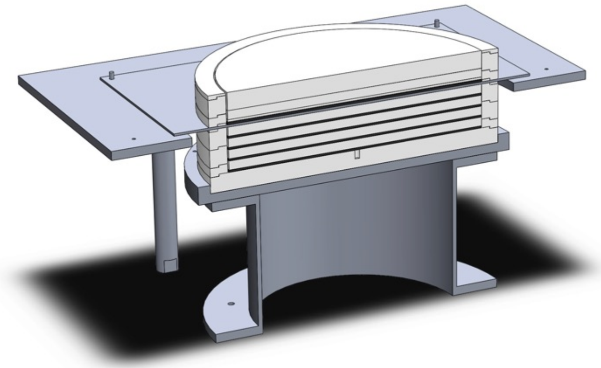
Case 1



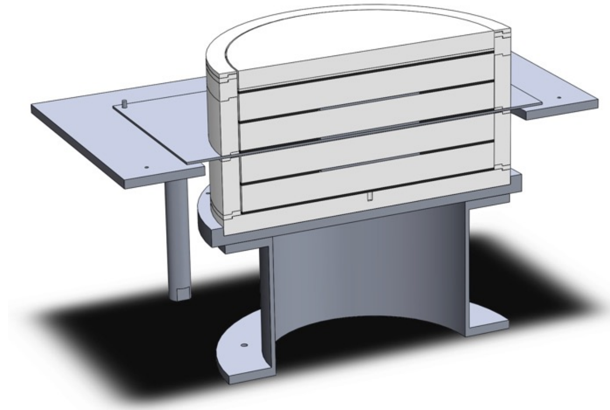
Case 2



Case 3



Case 4



Case 5

Uncertainty and Bias Calculations

- 27 parameters analyzed as part of the uncertainty analysis: Mass (7), Dimensional (13), Composition (6), and Temperature
- The largest source of uncertainty was consistently the core stack height, split between the upper and lower halves
  - Measured to within 1.5mm, typically <0.5mm
- Other significant sources include:
  - Lower reflector height
  - Membrane thickness
  - ^{235}U Enrichment (fast)

Uncertainty Calculation Results

- The dimensional uncertainty components were driven by the core stack height uncertainty

Uncertainty Components (# Components)	Case 1	Case 2	Case 3	Case 4	Case 5
Mass (7)	0.00019	0.00040	0.00032	0.00079	0.00014
Dimensional (13)	0.00081	0.00114	0.00102	0.00126	0.00098
Composition (6)	0.00046	0.00031	0.00021	0.00022	0.00030
Total (Quadrature)	**0.00095**	**0.00125**	**0.00109**	**0.00150**	**0.00104**

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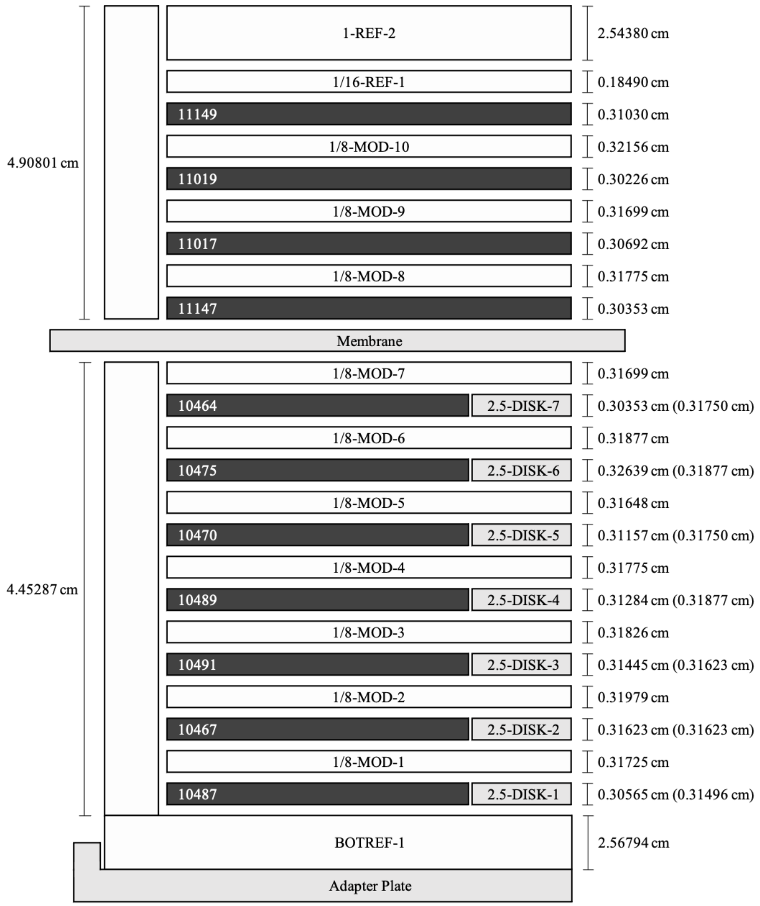
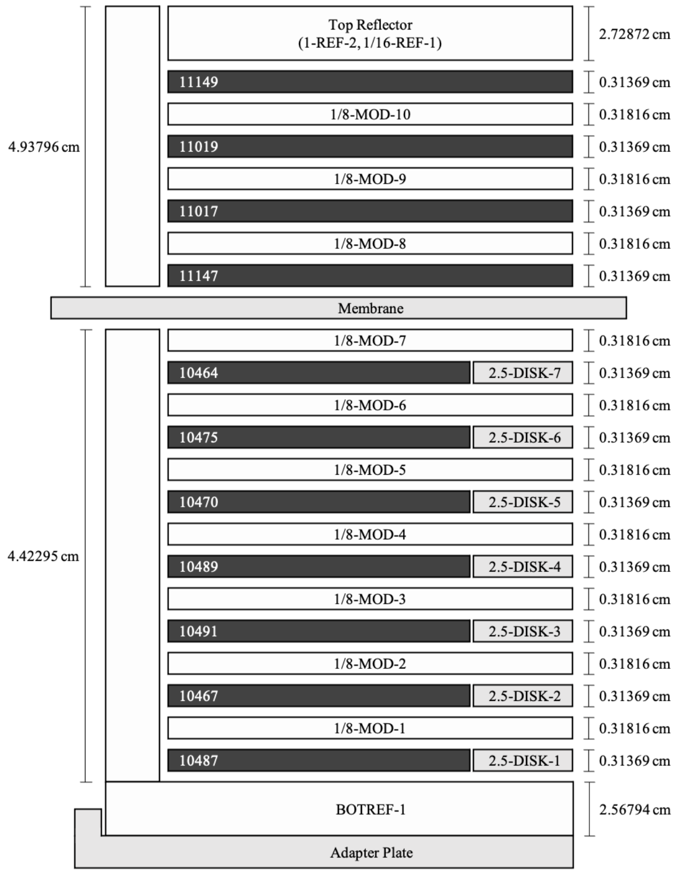
Detailed and Simplified Benchmark Models

Detailed Model



Simplified Model



Simplification and Bias Results

- Model simplifications include:
  - HEU and polyethylene impurity removal
  - Comet and experiment room removal
  - Average core stack part types (simplified model only)

Bias Component	Case 1	Case 2	Case 3	Case 4	Case 5
HEU Impurities	-0.00010	-0.00003	+0.00003	+0.00007	0.00000
Polyethylene Impurities	-0.00003	-0.00015	0.00000	-0.00012	-0.00005
Comet & Room Removal	+0.00214	+0.00229	+0.00204	+0.00203	+0.00159
Average Core Stacks (Simplified Only)	-0.00027	0.00029	0.00021	0.00002	-0.00027

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Experimental and Benchmark Model k_{eff}

- Experimental k_{eff} inferred based on period measurements and ENDF/B-VIII.0 delayed neutron parameters

Case	Experimental $k_{eff} \pm 1\sigma$	Bias in $k_{eff} \pm 1\sigma$	Benchmark Model k_{eff}
1	1.00026 ± 0.00001	0.00201 ± 0.00011	0.99825 ± 0.00011
2	1.00038 ± 0.00002	0.00211 ± 0.00011	0.99827 ± 0.00011
3	1.00067 ± 0.00003	0.00207 ± 0.00011	0.99860 ± 0.00011
4	1.00112 ± 0.00004	0.00198 ± 0.00011	0.99914 ± 0.00012
5	1.00094 ± 0.00004	0.00154 ± 0.00011	0.99940 ± 0.00012

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Results of Sample Calculations (C/E)

MCNP® 6.2.0 with Continuous Energy ENDF/B-VIII.0

- Calculated k_{eff} is slightly, but consistently under-predicting the experimentally inferred k_{eff}

Case	Detailed Model	Simplified Model
1	0.99511 ± 0.00095	0.99505 ± 0.00095
2	0.99469 ± 0.00125	0.99453 ± 0.00125
3	0.99441 ± 0.00109	0.99387 ± 0.00109
4	0.99485 ± 0.00150	0.99385 ± 0.00150
5	0.99724 ± 0.00104	0.99637 ± 0.00104

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Results of Sample Calculations (Fission Fractions)

MCNP® 6.2.0 with Continuous Energy ENDF/B-VIII.0

- Achieved goal of producing both a thermal and fast configuration with others in majority intermediate regimes

Case	Thermal (< 0.625 eV)	Intermediate (0.625 eV – 100 keV)	Fast (> 100 keV)
1	0.079	0.205	0.716
2	0.138	0.497	0.365
3	0.229	0.515	0.256
4	0.389	0.437	0.174
5	0.630	0.258	0.112

PRELIMINARY,
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2	[illegible]	0.497	0.365
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5	0.630	0.258	0.112

Case 1: 72% fast

Cases 2-4: 44% to 52% intermediate

Case 5: 63% thermal

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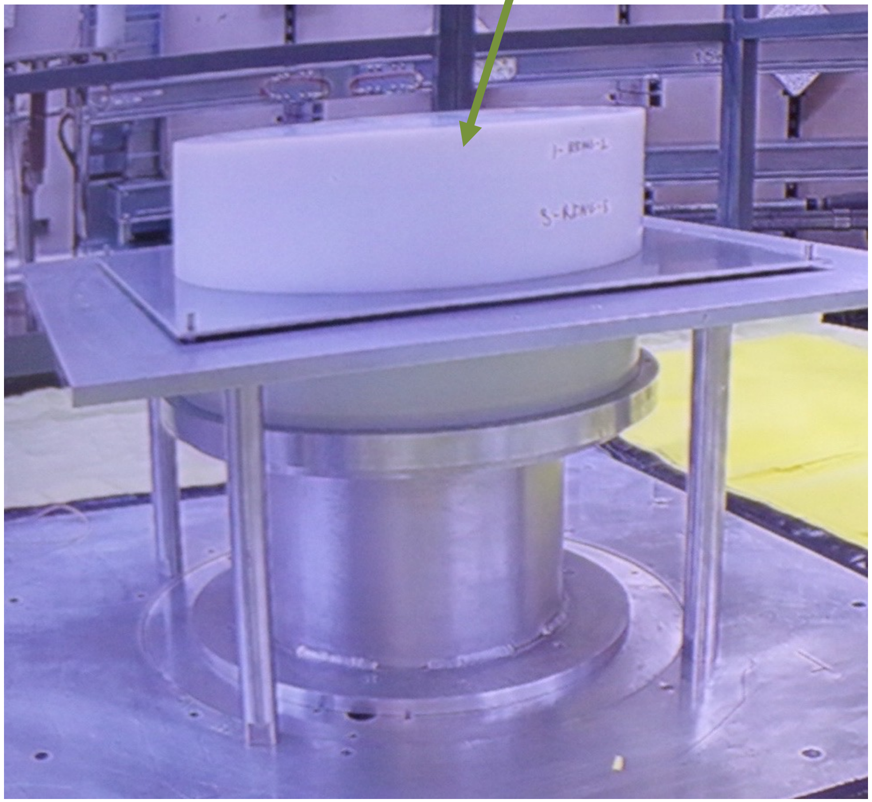
Conclusion and Future Work

- Accepted pending resolution of comments by the ICSBEP TRG in December 2021
  - Subgroup includes Catherine Percher, Dave Heinrichs, Michael Zerkle (NNL), and Jeffrey Favorite (LANL)
- Resolution of comments by March 31, 2022
- Plans to execute TEX-HEU-Hf variant of experiment design in FY22

Here's another photo of a self-sustaining nuclear chain reaction, wow!



Acknowledgments

- Funded by the U.S. Department of Energy's Nuclear Criticality Safety Program
- The NCSP C_EdT for IER-297 also includes Theresa Cutler (LANL), Michael Zerkle (NNL), William Marshall (ORNL), Joetta Goda (LANL), Catherine Percher (LLNL), and Mariya Brovchenko (IRSN)
- Executed at the National Critical Experiments Research Center under the operation of Los Alamos National Laboratory's Advanced Nuclear Technology Group (NEN-2)
- Experiment photos are courtesy of NEN-2
- The many comments from the members of the December 2021 ICSBEP TRG Meeting, especially the TEX-HEU Subgroup

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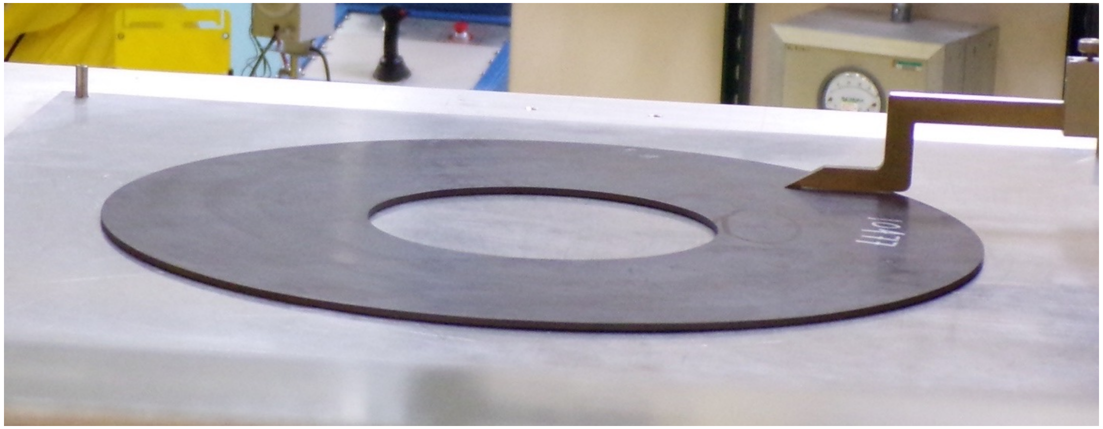
Experiment Photos



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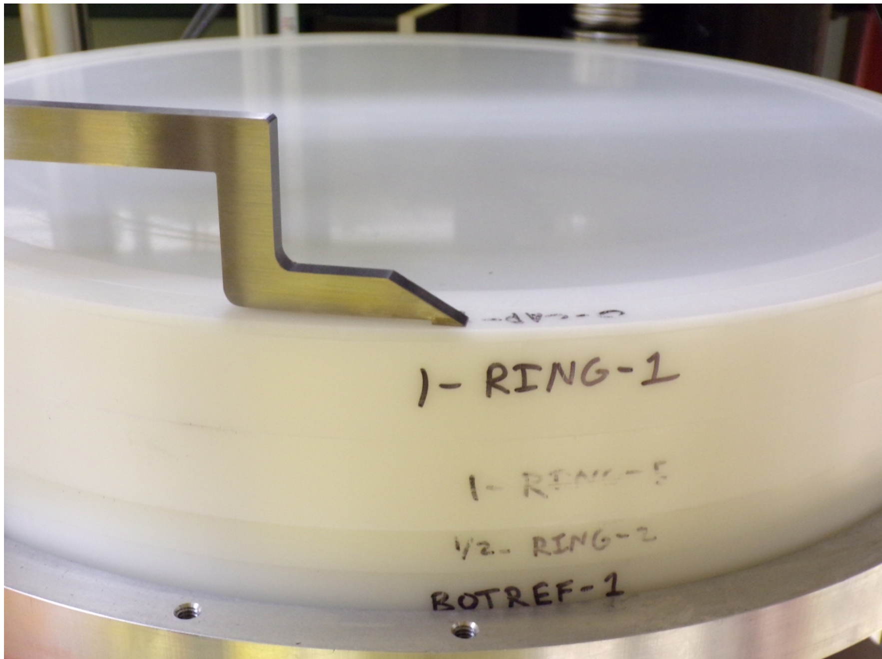
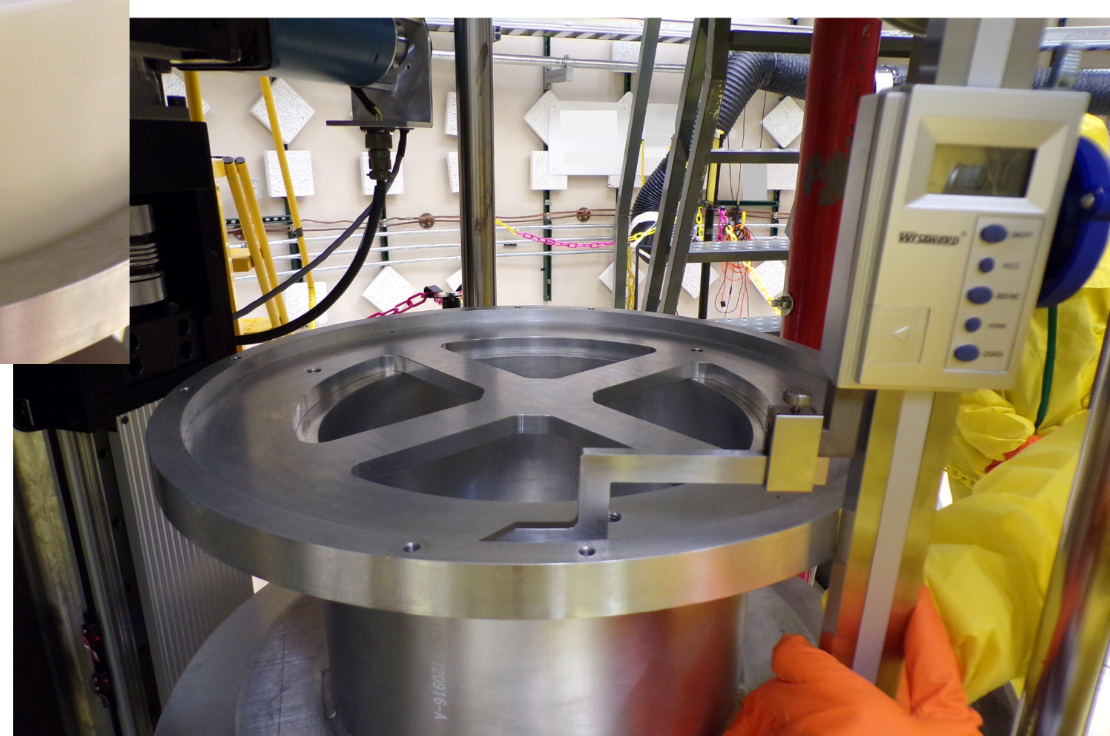
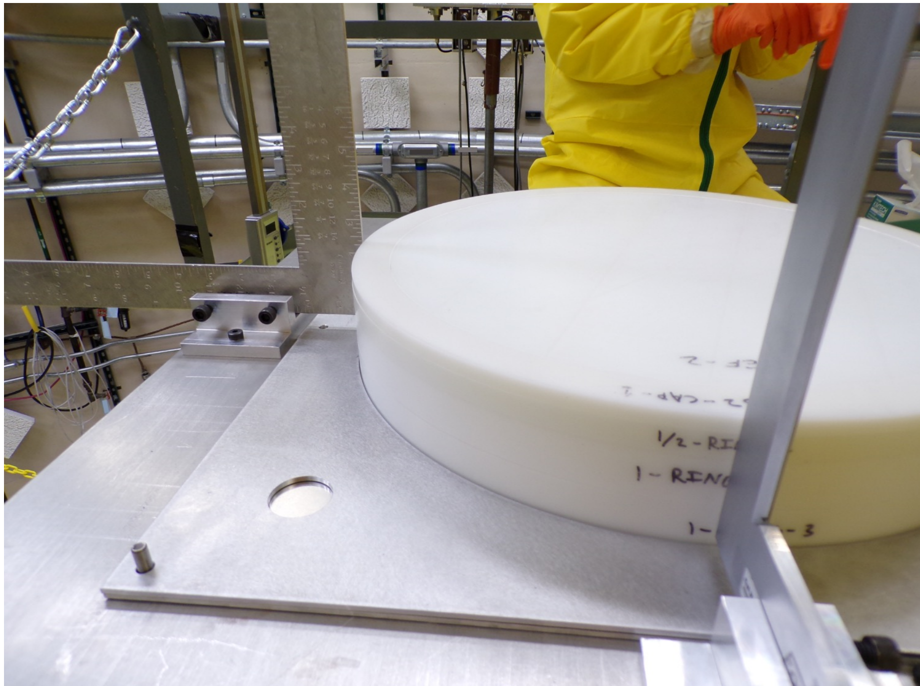


Measuring the reflector height of the lower assembly in the 1/2” configuration

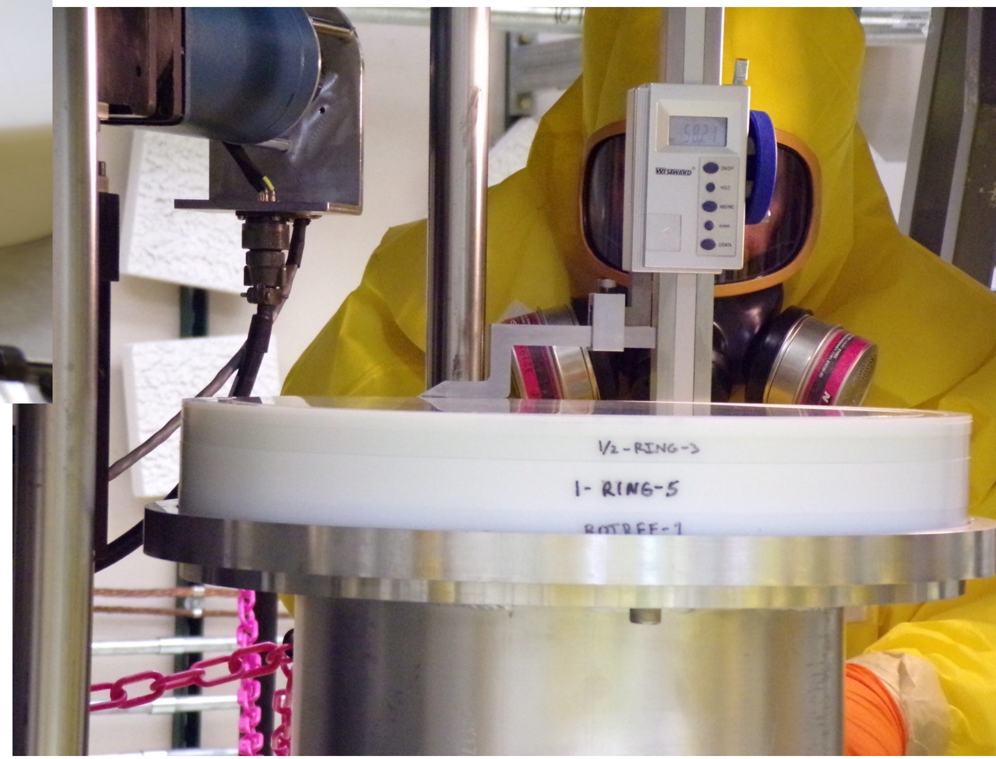


Zeroing the height gauge on the adapter plate

Experiment Photos



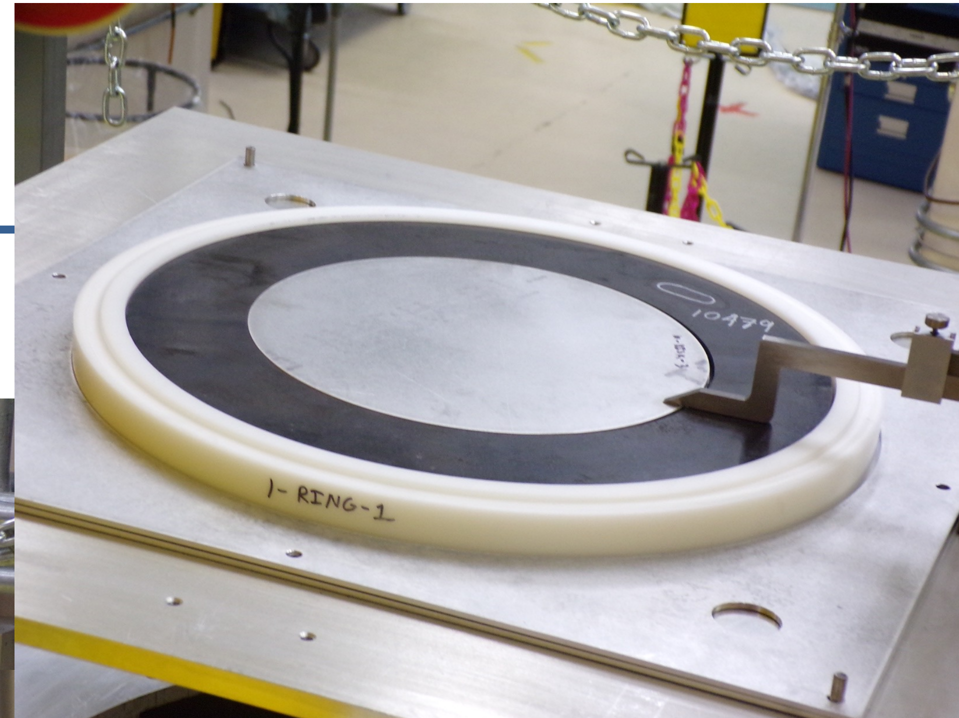
Experimenter using T-square brackets to align the reflector rings around the stack

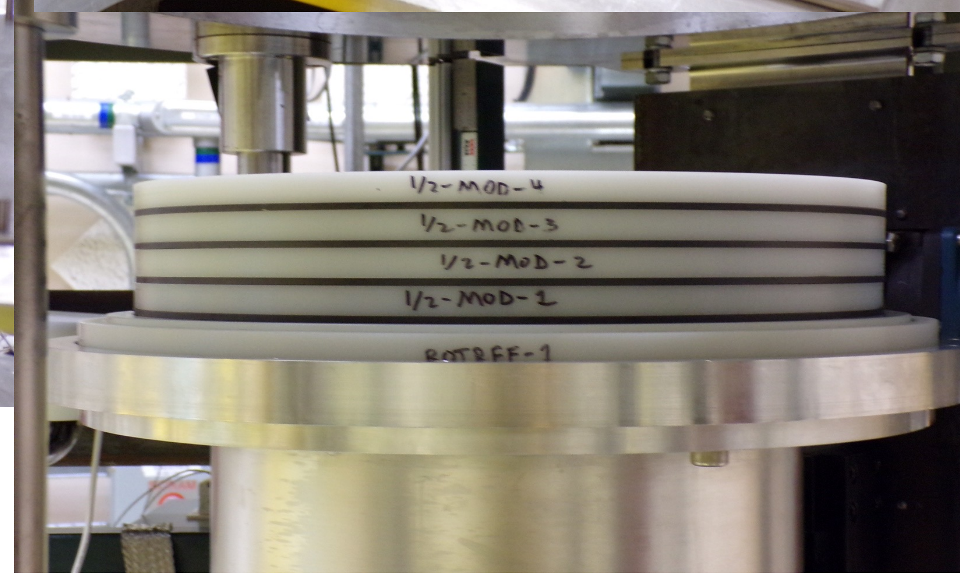


Experimenter measuring the overall height of the lower half of an experiment

Experiment Photos

10" HEU plate filled with an aluminum insert





Complete halves of two separate experiments without the surrounding reflector rings