Update on the Progress of KRUSTY Benchmark. (IER-299)

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Overview

- The main objective of the KRUSTY experiment is to evaluate the operational performance of a compact reactor that closely resembles the flight unit NASA will use for deep space exploration missions.

- Assess the bias in the multiplication factor, k_{eff}, due to the BeO and Mo neutron cross section data.

- Test the dynamic behavior of the reactor (transients).

- Verify the integrity of the fuel

KRUSTY test phases

Phase 1: Component Critical Measurements

- Critical configuration is determined
- BeO reflector worth measured
- B_4C control rod worth measurements
- Room temperature

Phase 2: Cold Critical Measurements

- Heat pipes installed
- Stirling engines installed
- Above items in a vacuum chamber
- Critical configuration found
- B_4C control rod worth measurements
- Room temperature

Phase 3: Warm criticals

- 15 cent free run,
- 30 cent run,
- 60 cent run
- Moderate temperature rise (<450°C)

Phase 4: High Temperature Operations

- Mission power profile is executed
- Significant temperature rise (800°C)

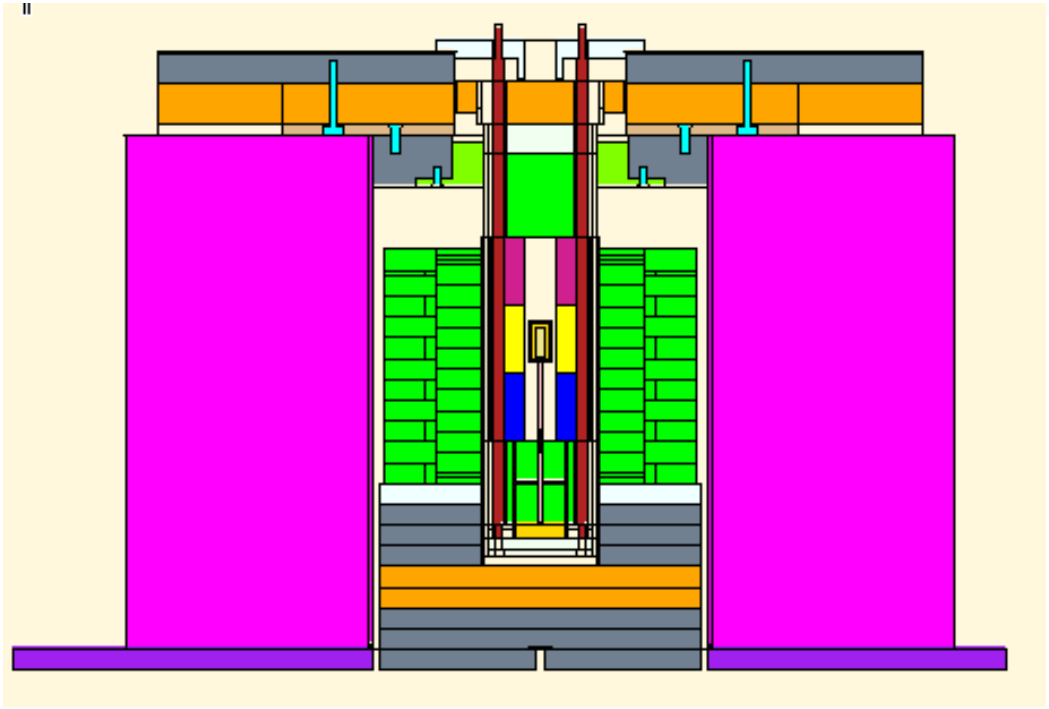
NCSP IER-299 CED-3B Documentation LA-CP-19-20000

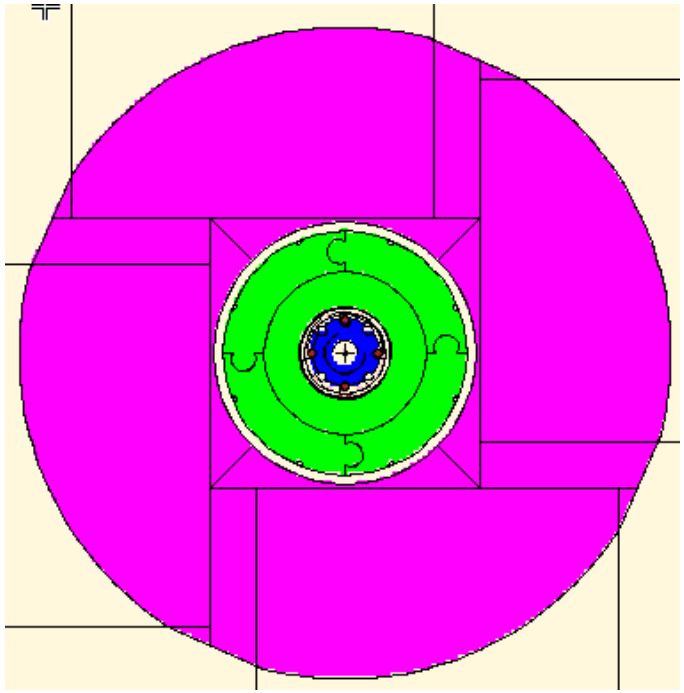
- Description of experiments
- Results of experiments
  - Phase #1 (60 configurations)
  - Phase #2 (54 configurations)
  - Phase #3 (Three runs)
- Assembly Procedure
- Material Data
- Log book
- Drawing package

Configurations Selected for the Component Critical Experiment

Sequential Operations Configuration	BeO Height (in)	Shim BeO (in)	B_4C Height (in)	Source Holder Installed	ρ Measured (cents)	Temperature (°C)
1. Baseline initial critical	11.25	0	0	Yes, Al	9.50	15.0
8. Added 1/8" BeO	11.375	0	0	Yes, Al	51.60	14.8
11. Removed source and source holder	11.25	0	0	No	2.30	15.7
25. Replaced upper bottom axial BeO reflector plug with Al plug	11.375	0	0	No	6.7	15.8
28. Replaced both (lower and upper) axial BeO plugs	11.5	0	0	No	28.1	16.1

MCNP Base model





k_{eff} = 0.99721 ± 0.00014

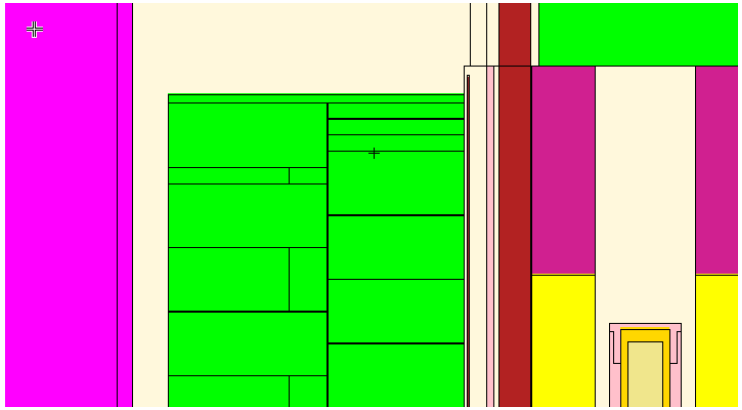
k_{eff} (exp) = 1.00067 ± 0.00007 at 15 ºC

β_{eff} = 0.00711

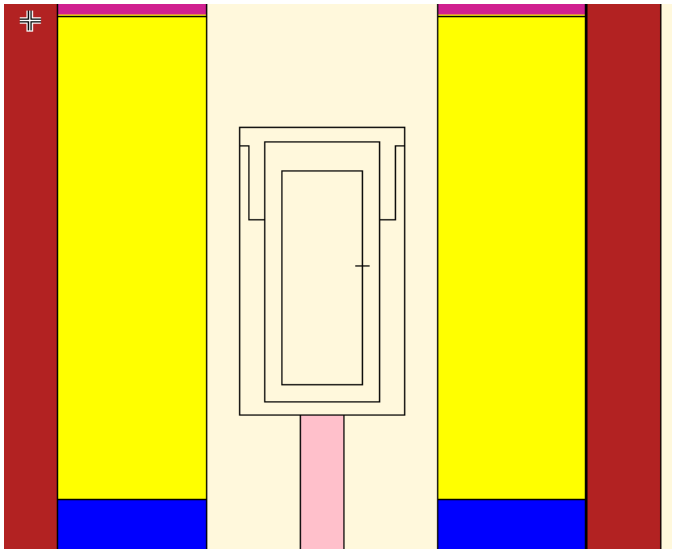
ENDF/B-VIII (293 K)

k_{eff} (no shield) = 0.94188 ± 0.00014 -$8.29

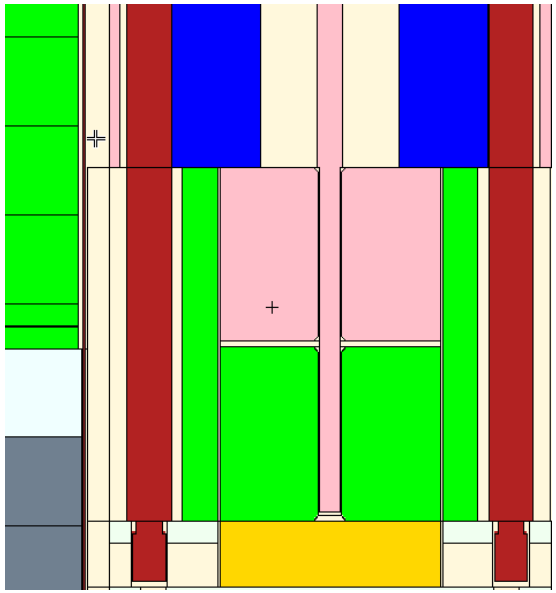
The other four cases



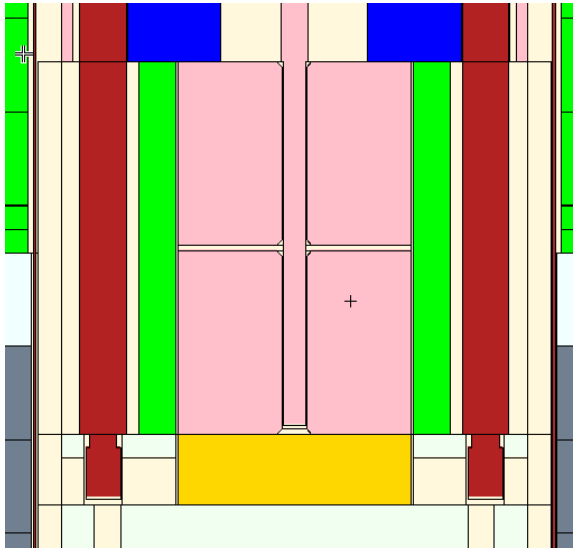
Adding 1/8” thick BeO radial reflector



Removing the source and source holder



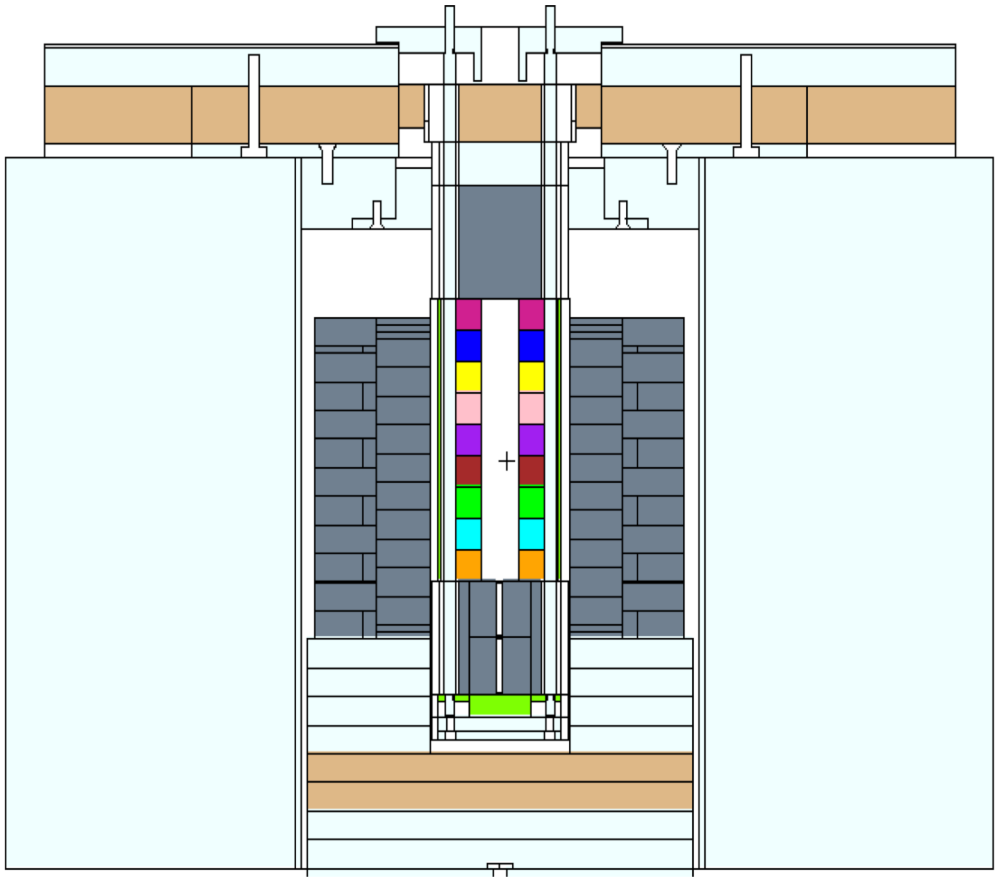
Replacing BeO plug #2 with Al



Replacing both BeO plugs with Al

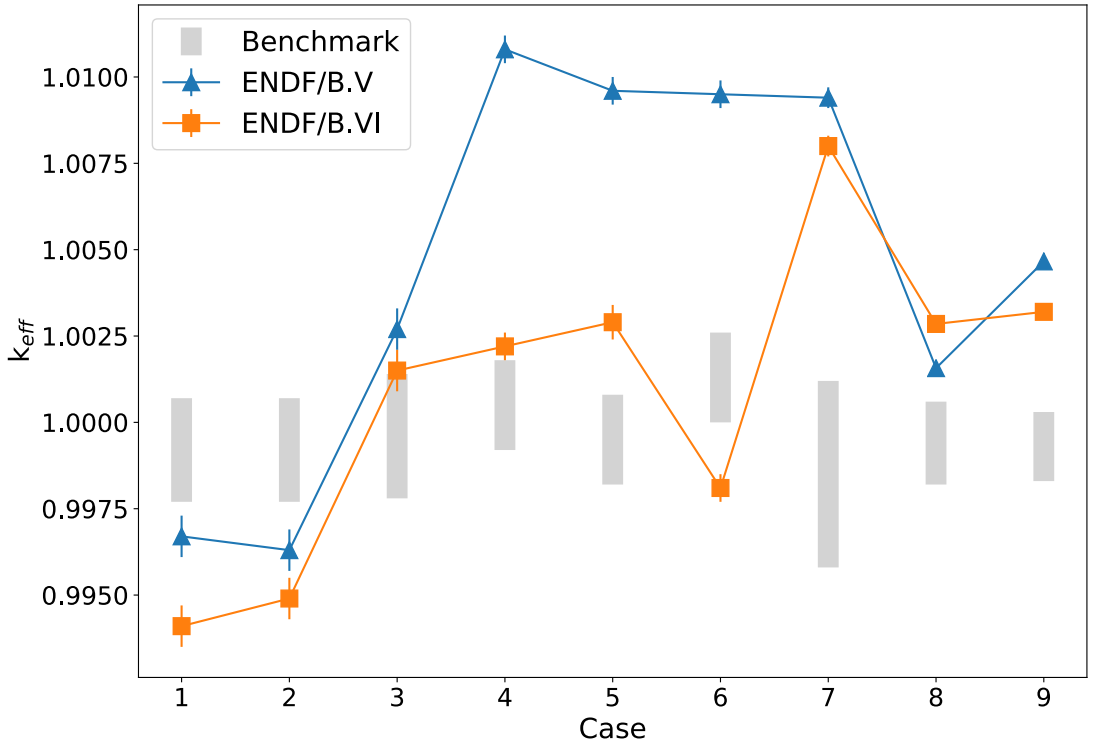
Component Critical Configuration

- **25 cm HEU Fuel**
  - 93.07% enriched
  - 7.65 wt% Mo
  - Cylindrical Annulus with 8 slots
- **BeO Reflectors**
  - Top, Bottom, and Rings
- **Shielding**
  - Outer shields and multi-layered top and bottom
- **Critical Configuration**
  - 28.575 cm
  - k_{eff} = 1.0006
  - Reactivity: 9.5 cents

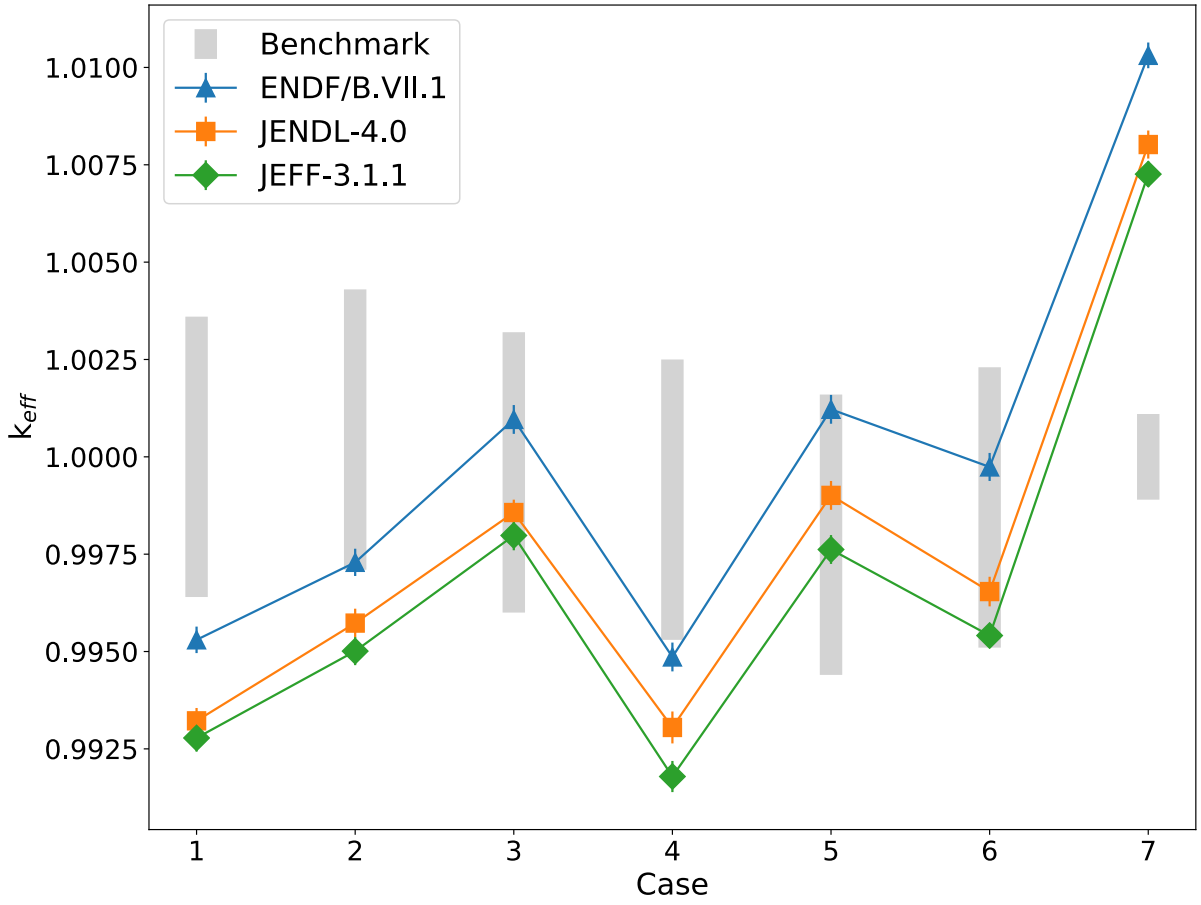


ICSBEP BeO Benchmarks

- 9 Experiments
- Large disagreement
  - KRUSTY will add new modern experiment



Molybdenum Benchmarks



- Seven Experiments
- Discrepancy

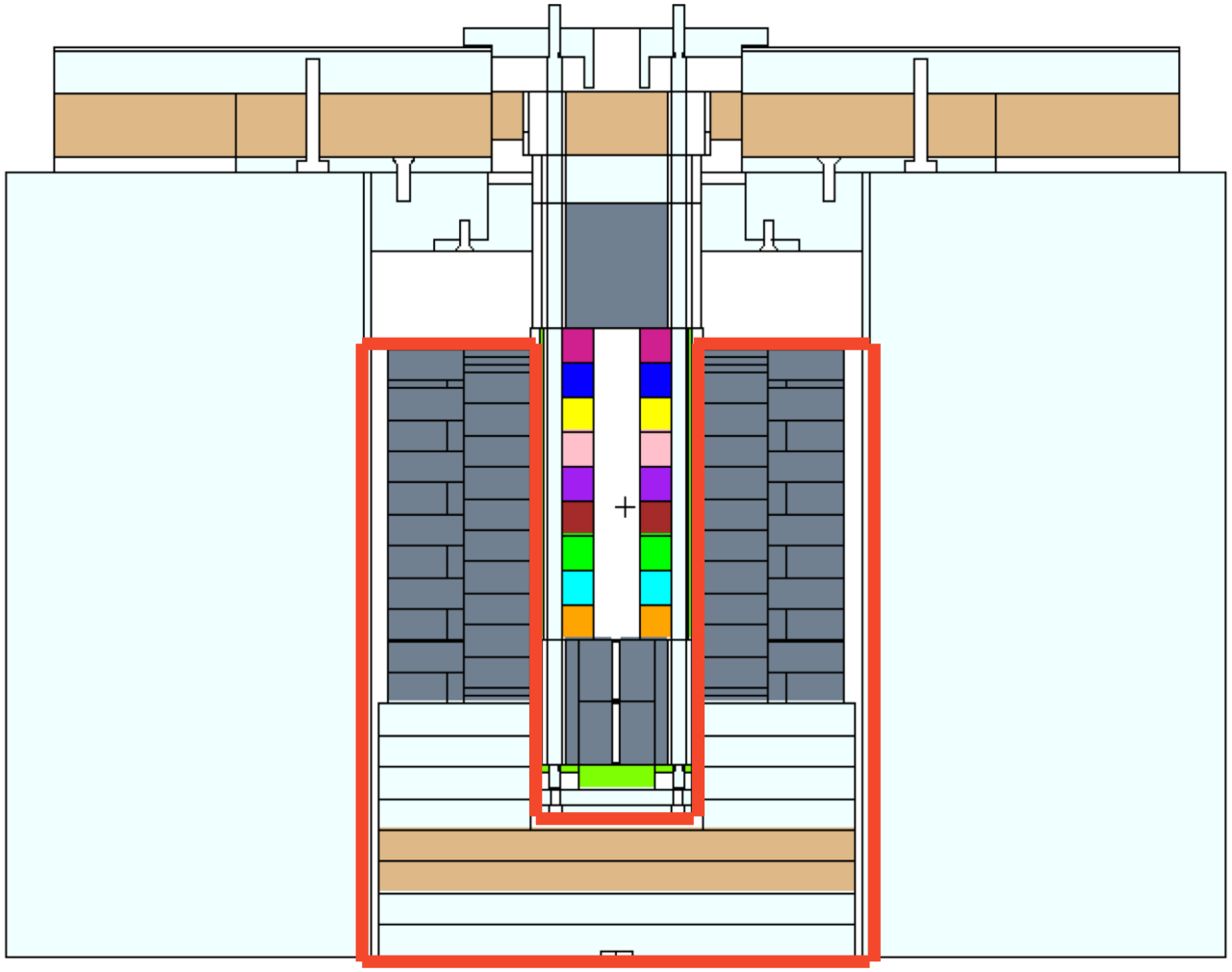
- KRUSTY may add much needed new point

Sensitivity and Uncertainty Evaluated Parameters

Mass & Dimensions	Positioning	Composition
HEU Core	Platen Height	Impurities
BeO Pieces	Radial Alignment	^{235}U Enrichment
SS Pieces	BeO Gaps	B_4C Enrichment
B_4C Shields	SS Shield Gaps	Air

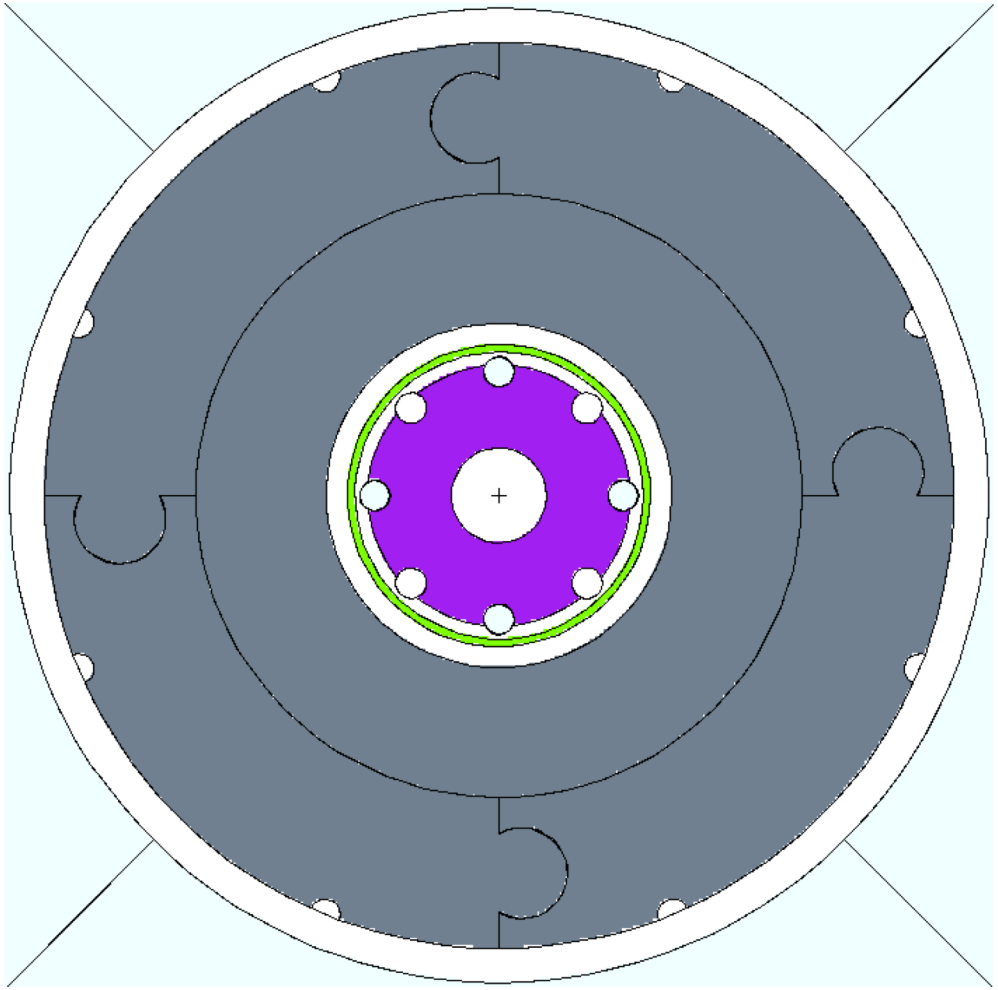
Positioning of the Platen Height

- BeO and SS-304 sit on a movable powered by a stepper motor



Positioning

- **Radial position**
  - Alignment of fuel
  - Jacket
  - BeO centering ring
  - Platen
- **BeO gaps**
  - Radial
  - Axial
  - Angle
- **Shield gaps**



Results

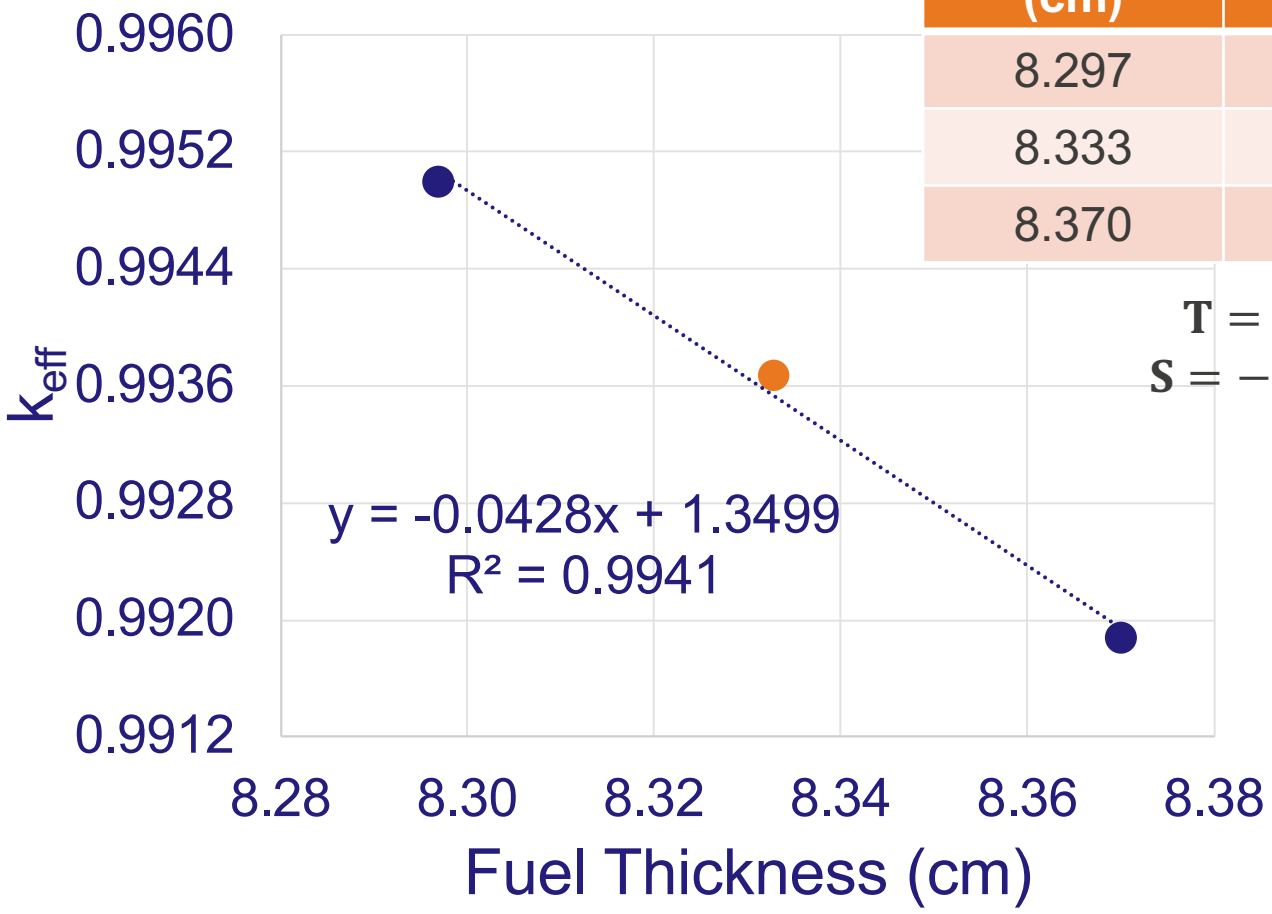
- Experimental k_{eff} 1.0006
- Modeled with MCNP6.2®
- Active Histories: 4 Billion
- My base model: 25 Million

Cross Section Library	k_{eff}	$\pm 1\sigma$	C-E (pcm)
ENDF-B/VIII.0	0.99687	0.00001	-373
ENDF-B/VII.1	0.99647	0.00001	-413
ENDF-B/VIII.0	0.99721	0.00015	-339

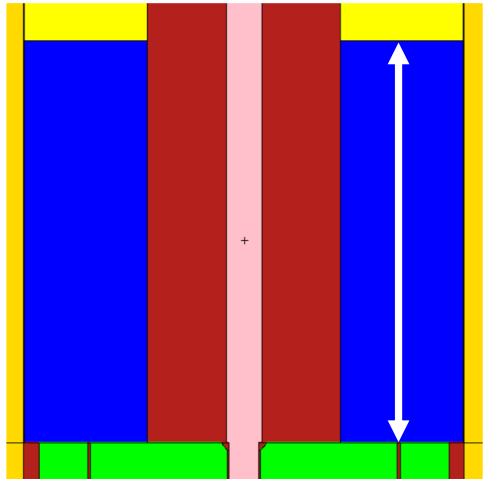
Case	k_{eff}	$\pm 1\sigma$	C-E (pcm)
Adding BeO	0.99966	0.00001	-404
Removing source and source holder	0.99671	0.00001	-345
Replacing BeO plug #1	0.99674	0.00001	-374
Replacing both BeO plugs	0.99814	0.00001	-386

Fuel Height Sensitivity

Thickness (cm)	k_{eff}	$\pm 1\sigma$
8.297	0.99499	0.00001
8.333	0.99366	0.00001
8.370	0.99187	0.00001

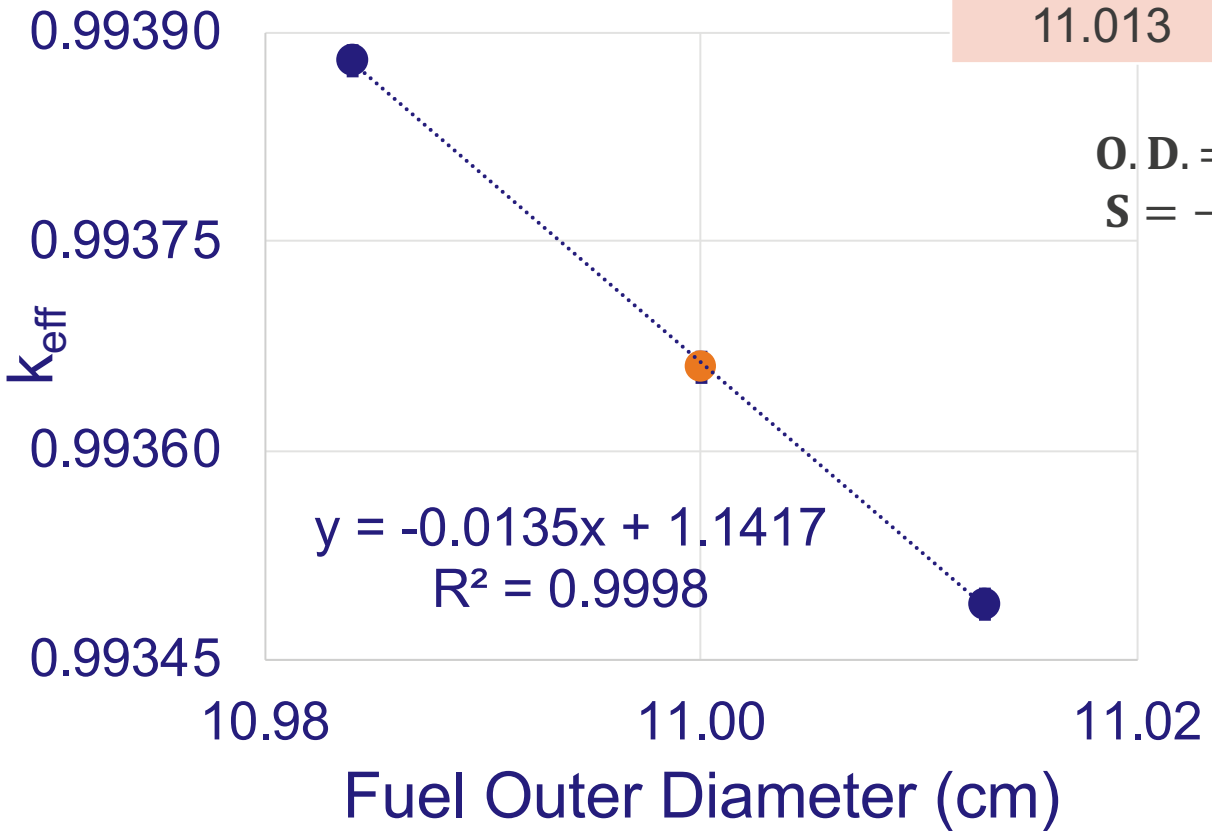


$$\mathbf{T = 8.333 \pm 0.007\ cm}$$
$$\mathbf{S = -0.35842 \pm 0.00162}$$

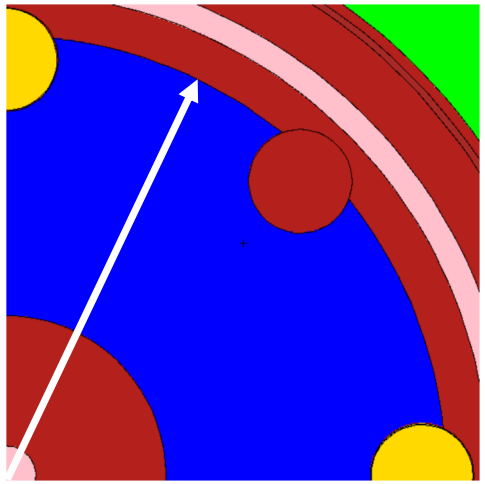


Fuel Outer Diameter Sensitivity

O.D. (cm)	k_{eff}	$\pm 1\sigma$
10.984	0.99388	0.00001
11.000	0.99366	0.00001
11.013	0.99349	0.00001



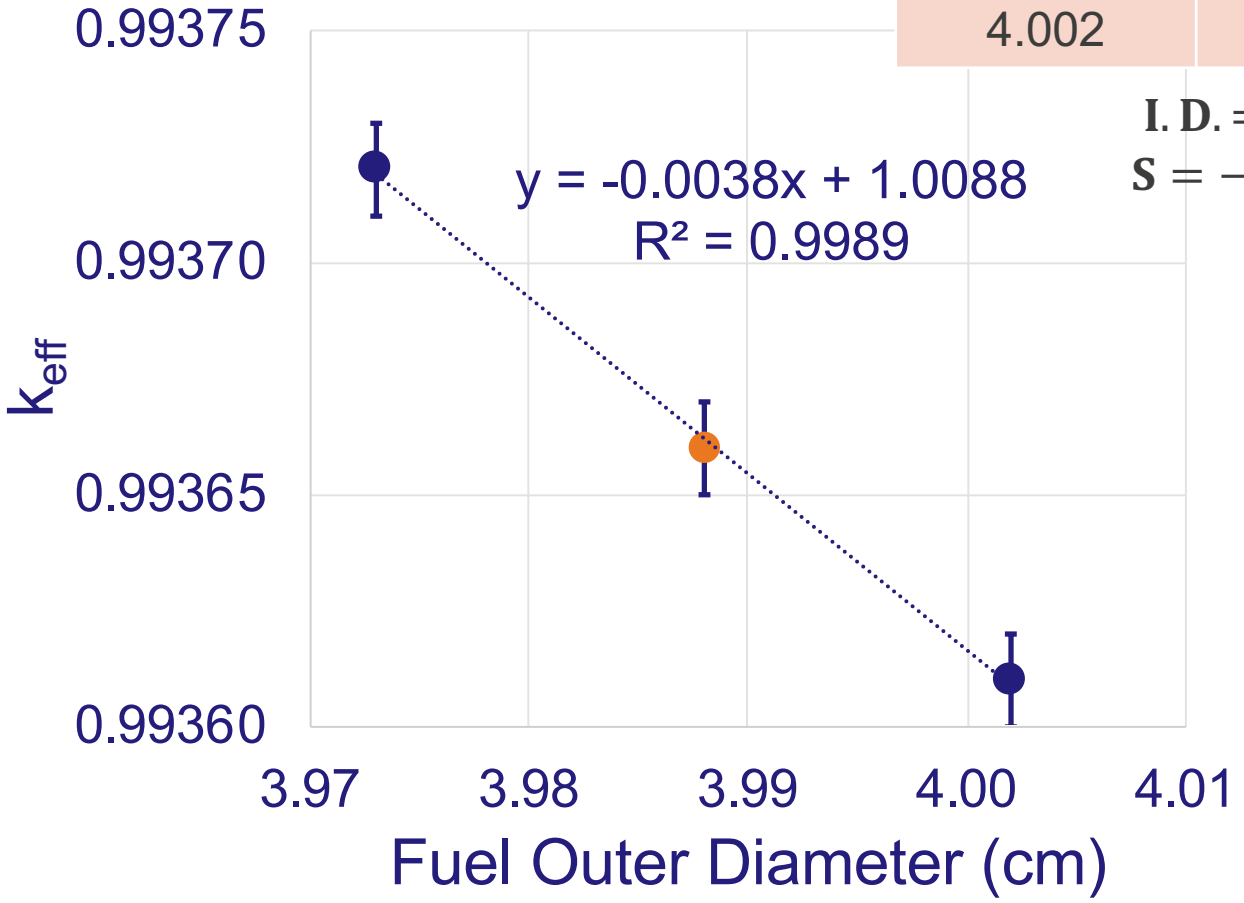
$$\mathbf{O.D.} = \mathbf{11.000 \pm 0.003\ cm}$$
$$\mathbf{S} = \mathbf{-0.14887 \pm 0.00540}$$

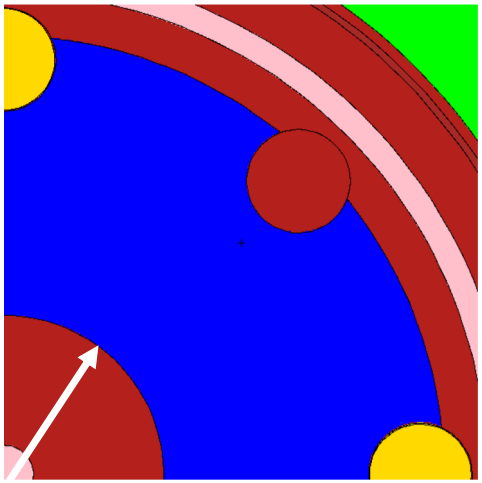


Fuel Inner Diameter Sensitivity

I.D. (cm)	k_{eff}	$\pm 1\sigma$
3.973	0.99372	0.00001
3.988	0.99366	0.00001
4.002	0.99361	0.00001

$$\mathbf{I.D.} = \mathbf{3.988 \pm 0.003\ cm}$$
$$\mathbf{S} = \mathbf{-0.01522 \pm 0.00196}$$





Summary

- **Benchmark will use ENDF/B-VIII.0**
  - Sensitive to fuel dimensions
    - Behaving as expected
  - Section 1 Completed
    - Tabulated:
      - Masses
      - Dimensions/Volumes
      - Densities
      - Compositions
  - Section 2 is underway
      - Fully outlined
      - Sources of error documented
      - Updated Fuel Mass Δk and S

  Section 3 is underway
      - Detailed model completed
      - Model of cases 2- 5 completed

Acknowledgement

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