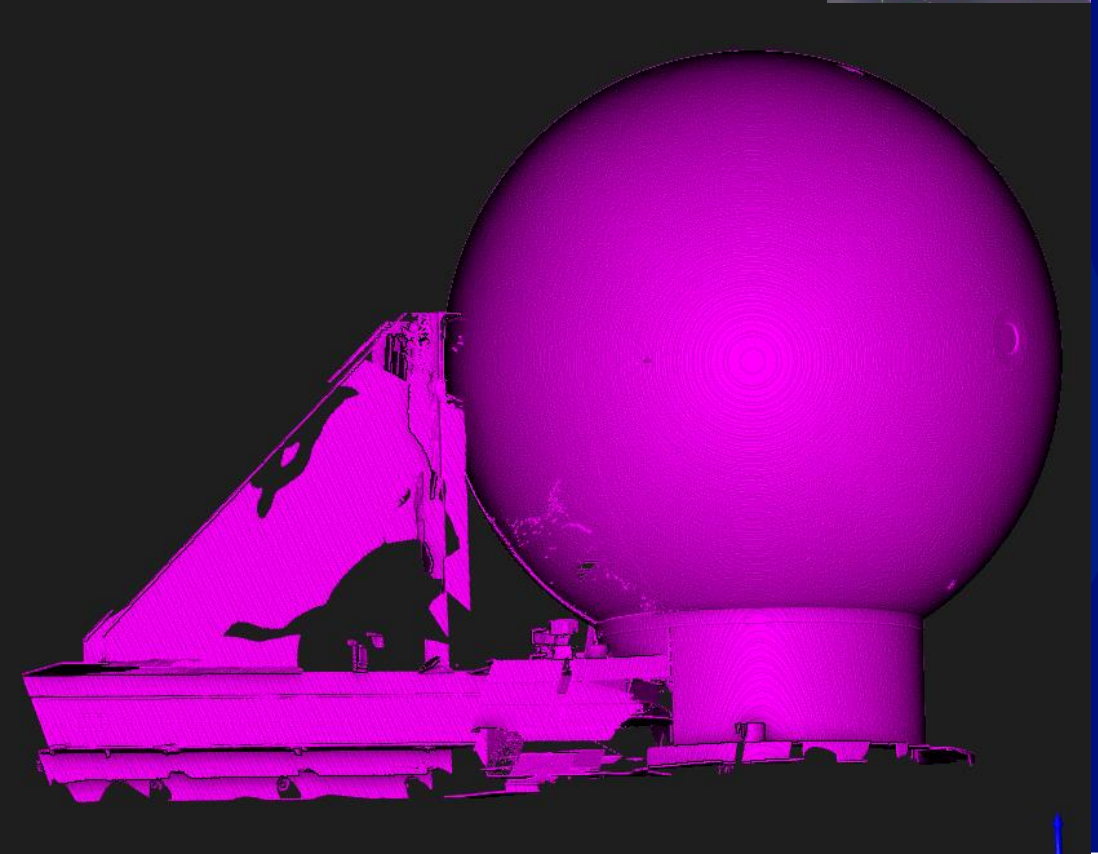

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IER 423: Flattop-HEU Benchmark Reevaluation Summary

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NEN-2

2024 NCSP Technical Program Review

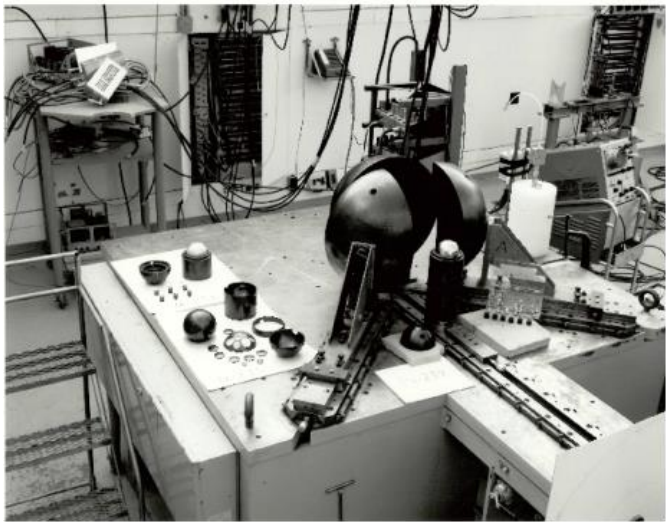
LA-UR-24-21037

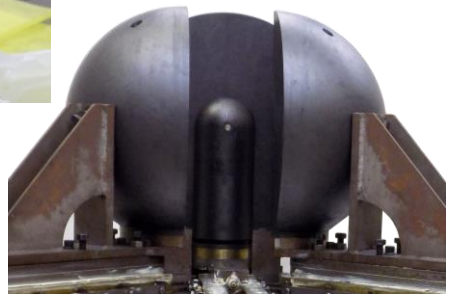
Overview

- Flattop Description
- Recap of Previous Work
- Modeling Work and Simplifications
- Uncertainty Analysis
- Conclusions
- Future Work

Flattop-HEU Description

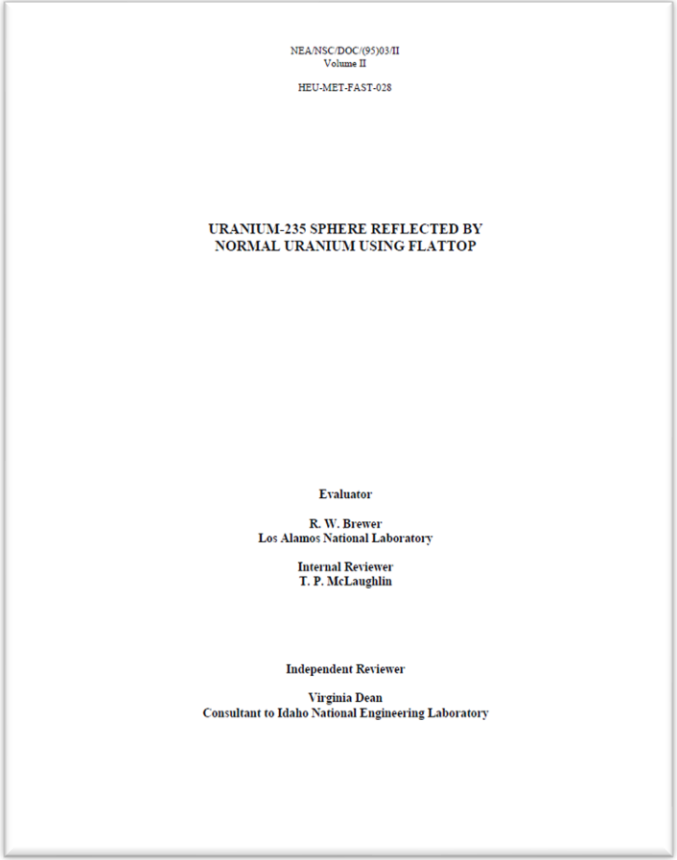
- 1950's:
  - Develop and validate nuclear data
  - One-dimensional, two-region models
- HEU Core
- NU Reflector and Control Rods
- Glory Hole
  - Allows for various configurations
  - Irradiation of samples to specified levels
- Today:
  - Fission Product and Activation Product Yield measurements; Replacement Measurements; DUFF; Nuclear Accident Dosimetry Testing; Nuclear Criticality Safety Training and Demonstrations





Previous Work

- Flattop-HEU benchmark written in 1999
  - HEU-MET-FAST-028
- Based on experiments from 1960's
- Written to *provide two diameters* for reflected critical mass
- Uncertainty:
  - Original Benchmark (1999)
    - ± 0.0030 (300 pcm)
  - Preliminary Reevaluation (2015)
    - ± 0.00157 (157 pcm)
    - +100% / -0%



NEA/NSC/DOC/(95)03/II
Volume II

HEU-MET-FAST-028

URANIUM-235 SPHERE REFLECTED BY
NORMAL URANIUM USING FLATTOP

Evaluator

R. W. Brewer
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Virginia Dean
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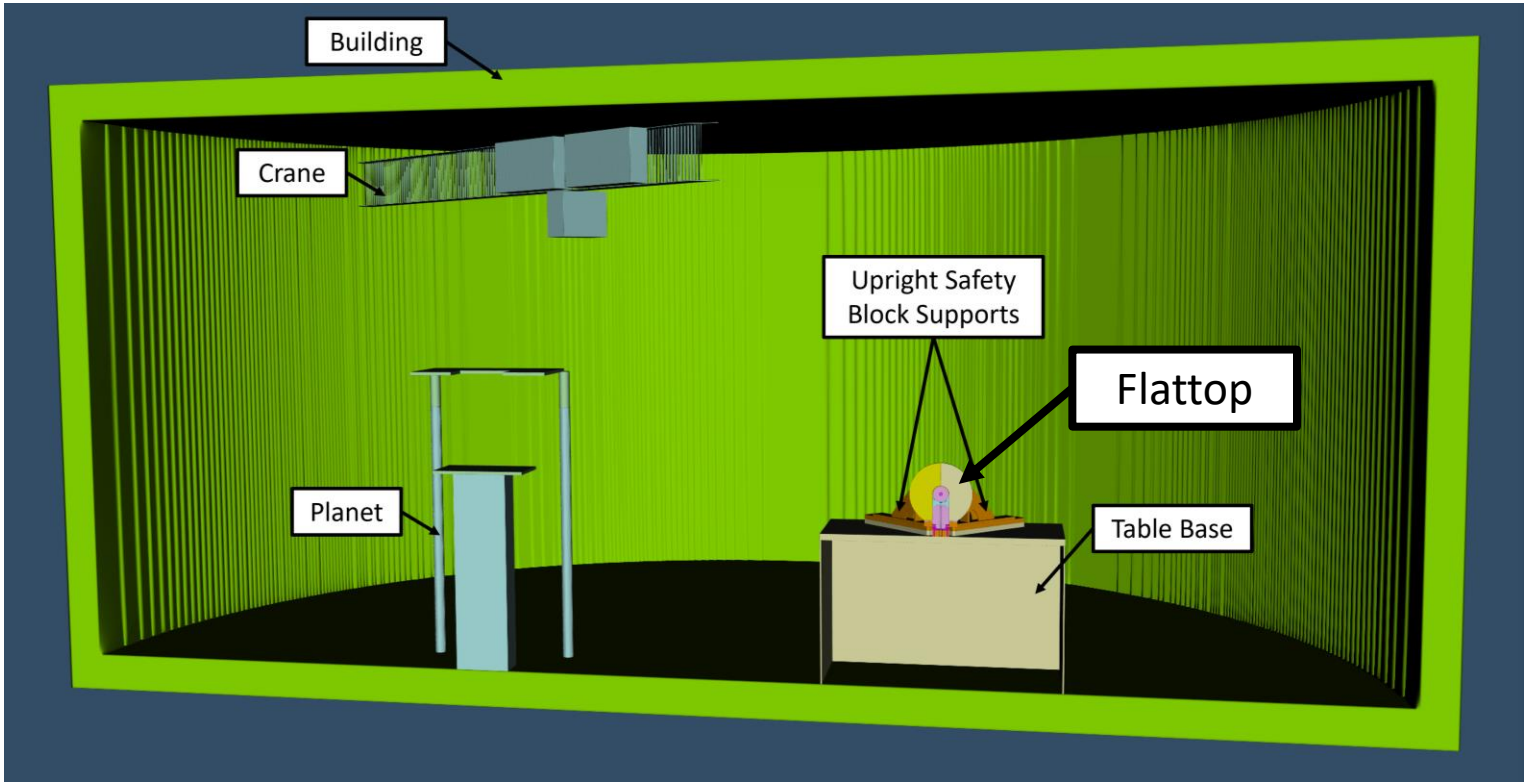
Benchmark Status and Timeline

- Sections 1 and 3 completed external review
- Section 2 in external review
- Section 4 on-going
- On track for submission very soon

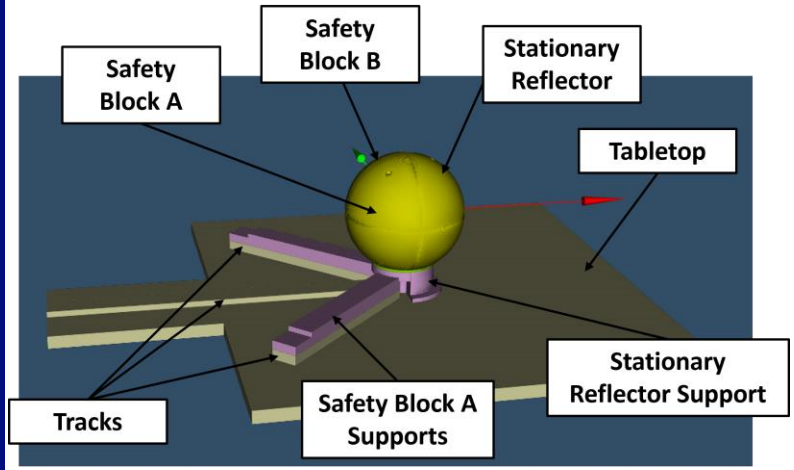
Full Model before Simplifications

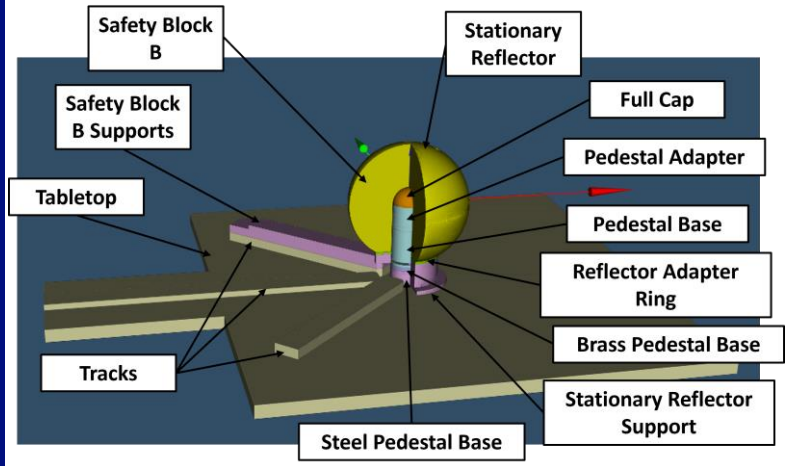


Axial Cross-section of building at X=0

Detailed Benchmark Model & Simplification Bias

Model	k_{eff}	Δk	Cumulative Δk
Detailed Model	1.000269	-	-
Add Gravity	1.000240	-0.000029	-0.000029
Add RTDs	1.000243	0.000003	-0.000026
Add Safety Block Supports	1.000291	0.000048	0.000022
Add Table Base	1.000308	0.000017	0.000039
Add Building	1.000341	-0.000018	0.000021
Add Crane	1.000380	0.000072	0.000093
Add Planet	1.000359	-0.000021	0.000072





Uncertainty Analysis

- Completed using [1]MCNP®6.3 and ENDF/B-VIII.0
- MCNP6.3 now reports to tenth of a pcm for k_{eff}
  - Parenthetical pcm values provided throughout for clarity
- Calculations had statistical uncertainty of ±0.000019 (1.9) or ±0.000018 (1.8)
- Final u_k < 0.000005 (0.5) deemed negligible
- Six categories examined:
  - Critical Measurement
  - Mass
  - Dimensions
  - Compositions
  - Positioning
  - Temperature

[1] MCNP® and Monte Carlo N-Particle® are registered trademarks owned by Triad National Security, LLC, manager and operator of Los Alamos National Laboratory. Any third-party use of such registered marks should be properly attributed to Triad National Security, LLC, including the use of the designation as appropriate. For the purposes of visual clarity, the registered trademark symbol is assumed for all references to MCNP within the remainder of this presentation.

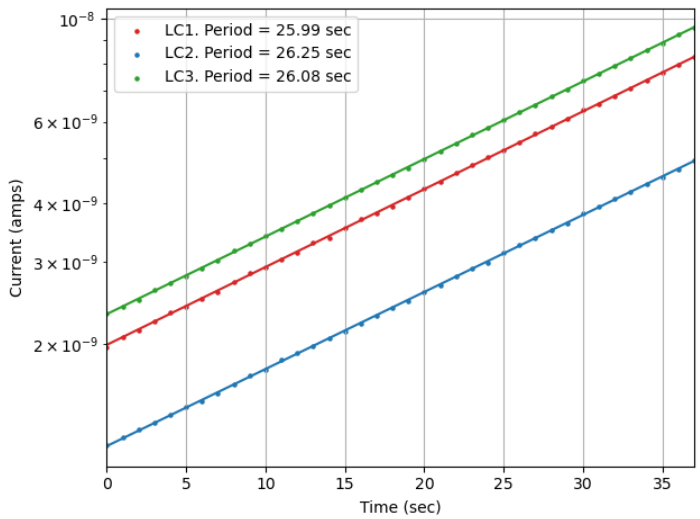
Criticality Measurement

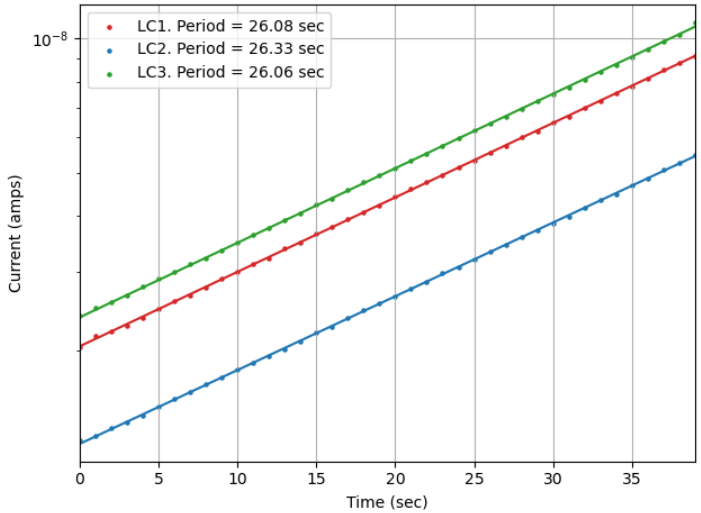
- Measured asymptotic reactor period

$$\rho = \frac{\Lambda}{T\beta_{eff}} + \sum_{i=1}^{P} \frac{\beta_i/\beta}{1+\lambda_i T}$$

$$k_{eff} = \frac{1}{1-\rho\beta_{eff}}$$

- Source of uncertainty evaluated:
  - Numerical fit
  - Reproducibility
  - Delayed neutron parameters
- **Overall Uncertainty: ± 0.000030 (3.0)**





Mass Uncertainty

- u_T is uncertainty in the mass
- Relative sensitivity obtained using iterated fission probability
  - KOPTS and KSEN cards

$$u_T = \sqrt{Nu_r^2 + N^2u_s^2 + \frac{Nr_r^2}{12}},$$

Component	k_{eff} Uncertainty
HEU Core	± 0.000649 (64.9)
Full Cap	± 0.000008 (0.8)
NU Mass Adjustment Button	± 0.000011 (1.1)
Stationary Reflector	± 0.000324 (32.4)
Safety Block A	± 0.000450 (45.0)
Safety Block B	± 0.000450 (45.0)
Control Rod E	± 0.000012 (1.2)
Control Rod F	± 0.000034 (3.4)
Control Rod G	± 0.000006 (0.6)

Dimension Uncertainty

- Sensitivity coefficients obtained through manual perturbation of dimensions
- Mass conserved by adjusting density
  - Volumes calculated analytically

Component	k_{eff} Uncertainty
HEU Core	± 0.000086 (8.6)
Full Cap	± 0.000013 (1.3)
HEU Mass Adjustment Button	± 0.000010 (1.0)
Glory Hole Filler Pieces	± 0.000011 (1.1)
Stationary Reflector	± 0.000018 (1.8)
Safety Block	± 0.000013 (1.3)
Control Rod	± 0.000008 (0.8)
Reflector Sleeve	± 0.000011 (1.1)
Pedestal Adapter	± 0.000038 (3.8)
Pedestal Base	± 0.000017 (1.7)
NU Mass Adjustment Button	± 0.000007 (0.7)
Reflector Adapter Ring	± 0.000006 (0.6)
Lifting Fixture Plug	± 0.000013 (1.3)
Brass Pedestal Base	± 0.000023 (2.3)
Stationary Reflector Base	± 0.000005 (0.5)
Safety Block Spacer	± 0.000010 (1.0)
Steel Pedestal Base	± 0.000016 (1.6)
Safety Block Supports	± 0.000014 (1.4)
Tracks	± 0.000007 (0.7)

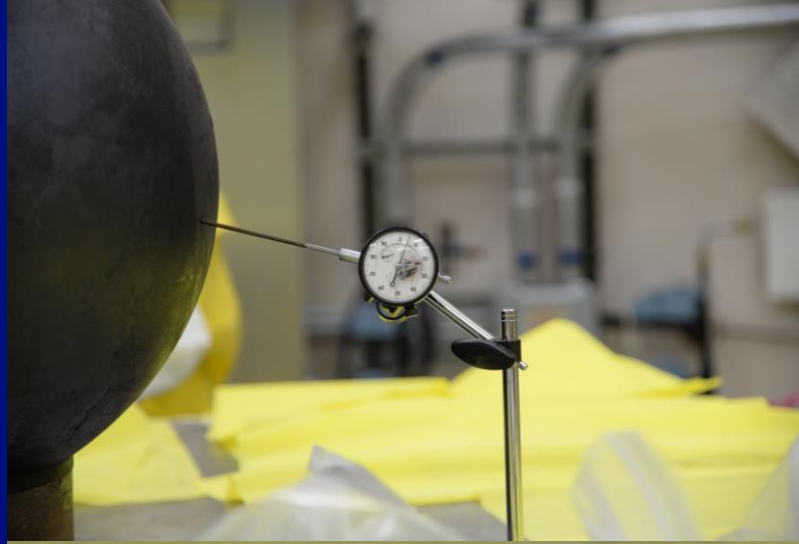
Composition Uncertainty

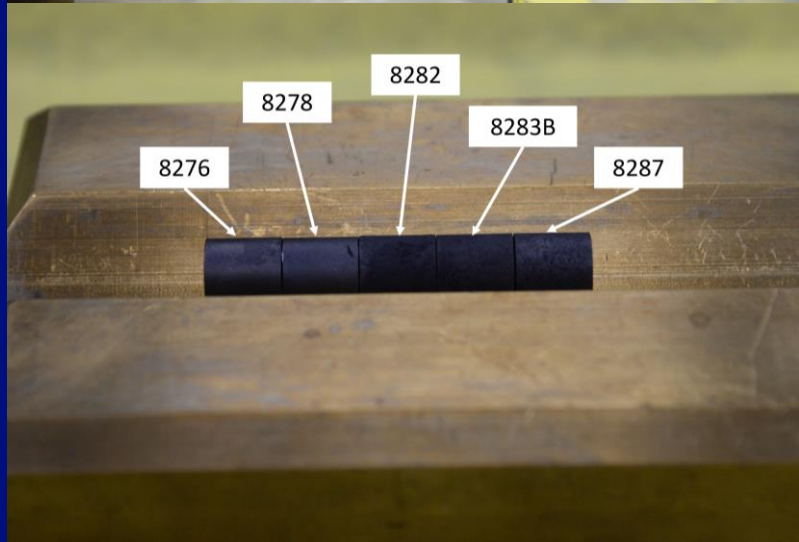
- Relative sensitivity obtained using iterated fission probability
  - KOPTS and KSEN cards
- Uranium impurities for Flattop not provided
  - Impurities from Jemima plates assumed
  - Scaled on a per U-235 atom
  - Applied to HEU and NU components simultaneously

Components	k_{eff} Uncertainty
Uranium Impurities	± 0.000032 (3.2)
HEU Core	± 0.000257 (25.7)
Full Cap	± 0.000014 (1.4)
Pedestal Adapter	± 0.000033 (3.3)
Pedestal Base	± 0.000009 (0.9)
Stationary Reflector	± 0.000111 (11.1)
Safety Block A	± 0.000065 (6.5)
Safety Block B	± 0.000064 (6.4)
Control Rod F	± 0.000010 (1.0)

Positioning Uncertainty

- Positioning aided by bolts, pins, tracks, and interlocking features
- Categories:
  - Safety Block Gap
  - Control Rod Insertion Point
  - Glory Hole Piece Alignment
  - Reflector Sleeve Insertion
  - Pedestal Seated Position
- **Uncertainty: ± 0.000069 (6.9)**





Total Uncertainty

- **Final combined uncertainty: ± 0.001019 (101.9)**
- Recall:
  - Original benchmark: ± 0.0030 (300)
  - Preliminary reevaluation: ± 0.00157 (157)
    - +100% / -0% error
- Successfully met objective to better characterize uncertainty of experiment
- Additionally, final uncertainty on same order of magnitude as modern benchmark evaluations despite limitations on not disassembling the reflectors

Summary of Results

Table 273. Sample Calculation Results for the Detailed Model.

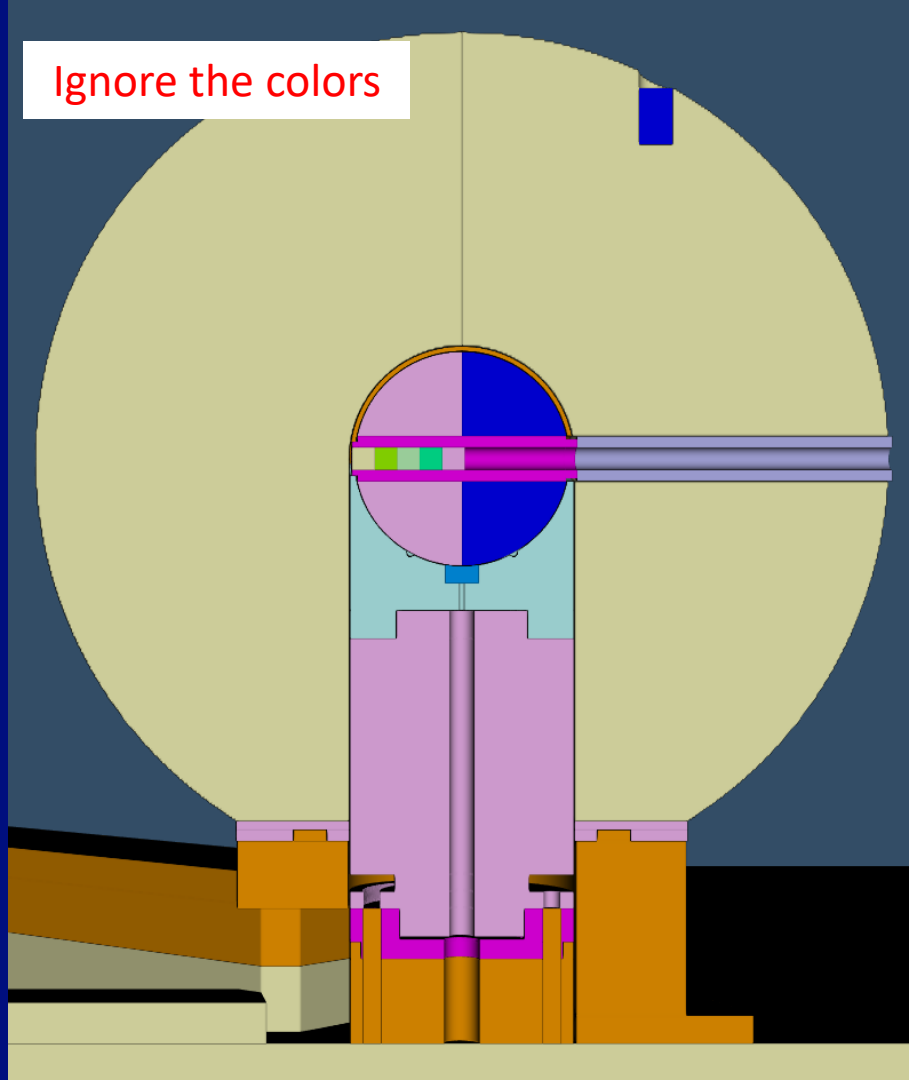
Benchmark	MCNP6.3 ENDF/B-VIII.0	C-E (pcm)	MCNP6.3 ENDF/B-VII.1	C-E (pcm)
1.001582 ± 0.001021	1.000264 ± 0.000018	-131.8	1.002317 ± 0.000018	73.5

Table 274. Sample Calculation Results for the Simplified Model.

Benchmark	MCNP6.3 ENDF/B-VIII.0	C-E (pcm)	MCNP6.3 ENDF/B-VII.1	C-E (pcm)
1.002491 ± 0.001024	1.001158 ± 0.000018	-133.3	1.003172 ± 0.000019	68.1

Conclusions and Future Work

- Completed benchmark reevaluation
  - Pending TRG review in April
- Final combined uncertainty: ± 0.001019 (101.9)
- Successfully met objective to better characterize uncertainty of experiment
- Additionally, final uncertainty on same order of magnitude as modern benchmark evaluations despite limitations due to not disassembling the reflectors



Acknowledgements

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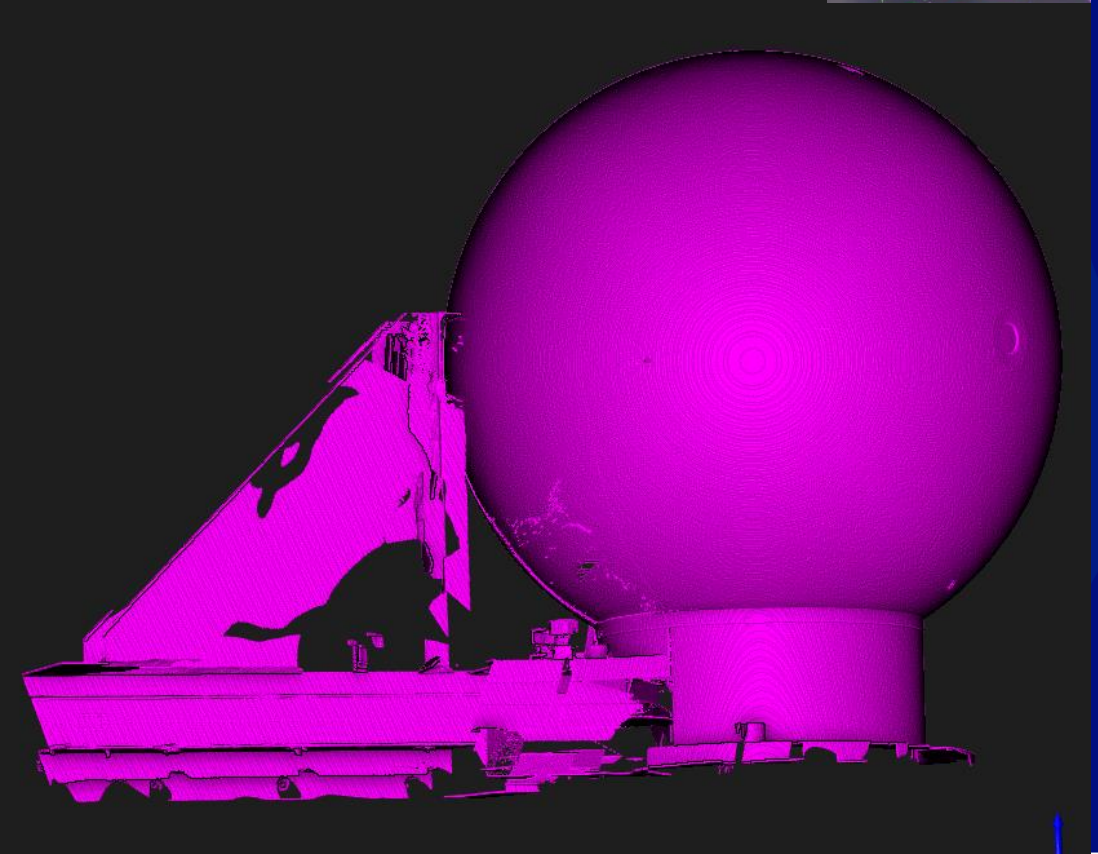

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Questions?

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