

IER 488: MUSiC (Measurement of Uranium Subcritical and Critical)

Critical Configurations Benchmark Update

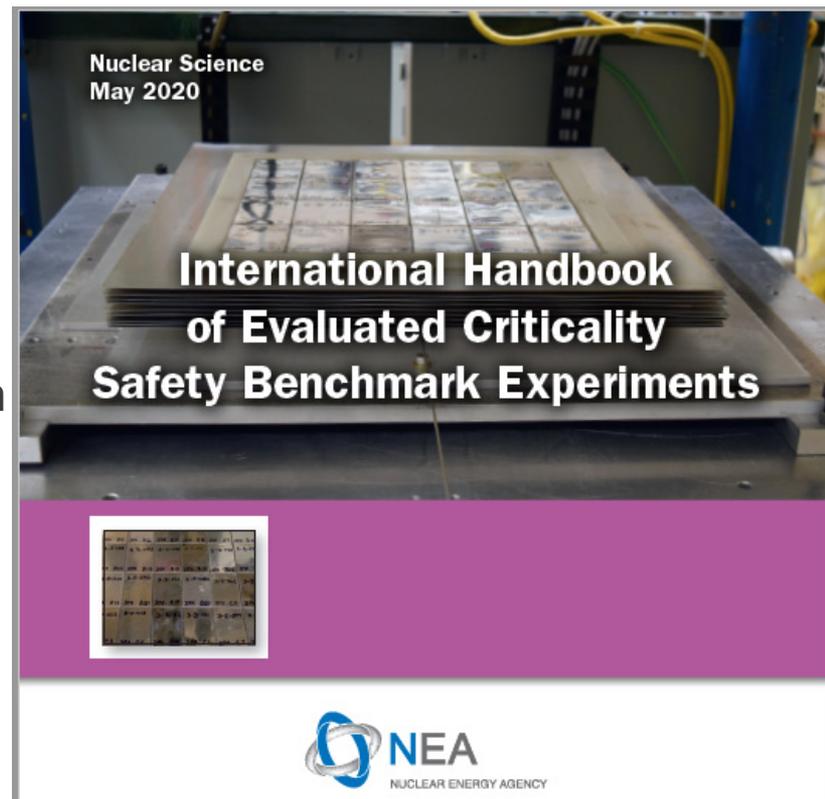
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February 22th, 2023



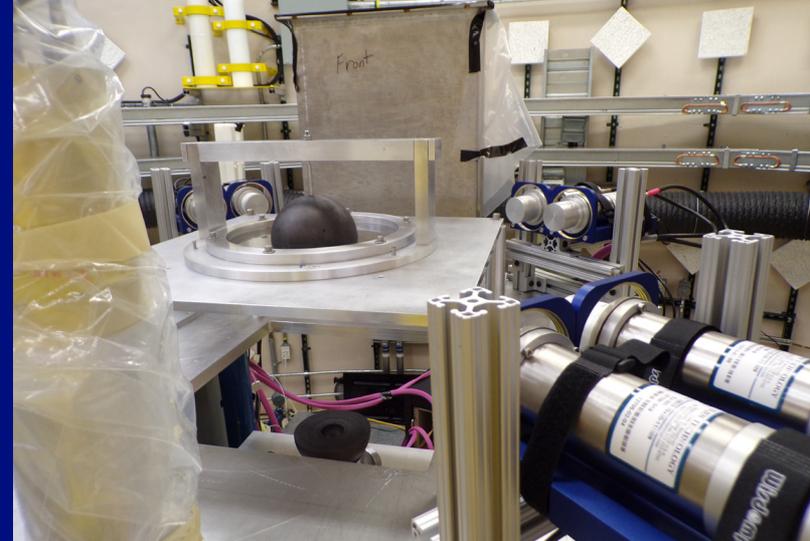
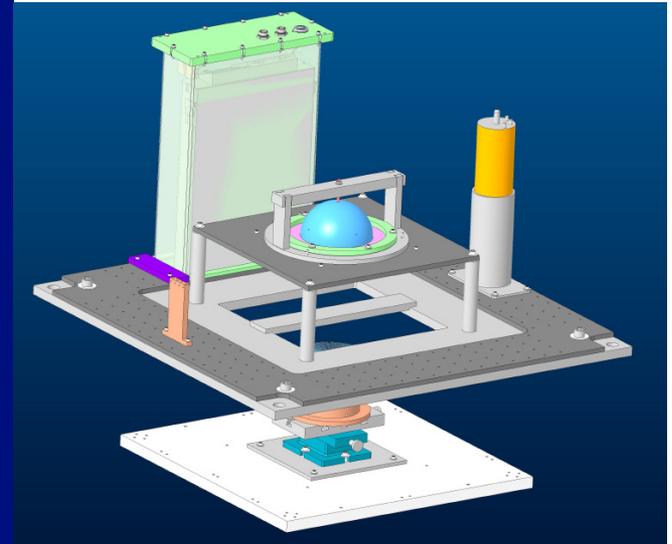
Introduction/Motivation

- **The International Criticality Safety Benchmark Evaluation Project (ICSBEP) Handbook provides benchmark experiments crucial for nuclear data validation**
 - Large number of existing benchmarks, but largely based on historical benchmarks written decades after the experiment was performed
 - Standards for thoroughness and precision have increased quite dramatically
 - Section 2 in HEU-MET-FAST-001(Lady Godiva): 3 pages; HEU-MET-FAST-104 (MUSIC): 165 pages
- **As a recent experiment evaluated to modern standards, MUSIC could serve as a valuable tool to validate ^{235}U data**
 - IER-153 Prompt Fission Uranium Neutron Spectrum



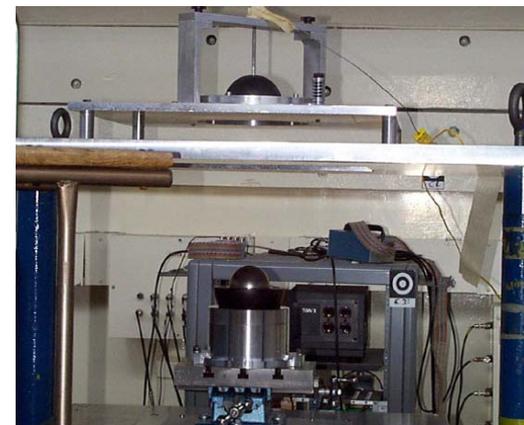
Experiment Overview

- Performed at NCERC in December 2020-March 2021
- Increasing number of Rocky Flats Shells on the Planet Vertical Lift Machine
 - Highly Enriched Uranium hemishells
- Experiment configurations ranged from deeply subcritical to delayed supercritical
- Tested with no external source, a ^{252}Cf , and a D-T neutron generator
- Detectors included a NoMAD, small ^3He tubes, and multiple scintillator systems from LANL and University of Michigan
- Collaboration with Institut de radioprotection et de sûreté nucléaire (IRSN)



Rocky Flats Shells

- Used from the 1960's in the Rocky Flats Critical Mass Laboratory
- Each nesting hemishell is approximately 3 mm thick
- Mass range from ~300 g to ~3600 g each
- Previously featured in multiple critical experiments



Bob Rothe, "Extrapolated Experimental Critical Parameters of Unreflected and Steel-Reflected Massive Enriched Uranium Metal Spherical and Hemispherical Assemblies," INEEL/EXT-97-01401

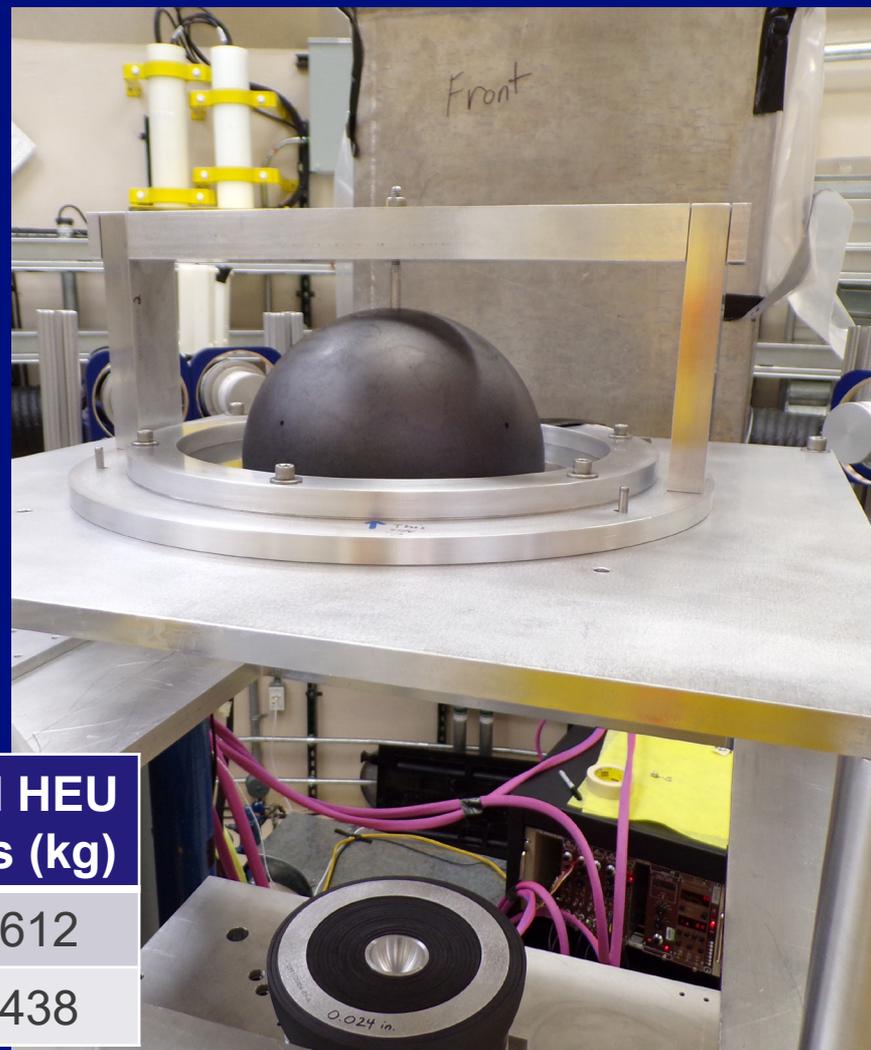
MUSIC Subcritical and Critical Configurations

Configuration	Rocky Flats Shells	Mass (kg)
1	2-24	13.0428
2	3-30	21.6432
3	3-34	29.0415
4	3-38	37.9617
5	3-40	42.9722
6	3-42	48.4099
7	3-44	54.2785
8*	3-46	60.612
9*	3, 5-46	60.438
10	9-46	59.2075



Configurations

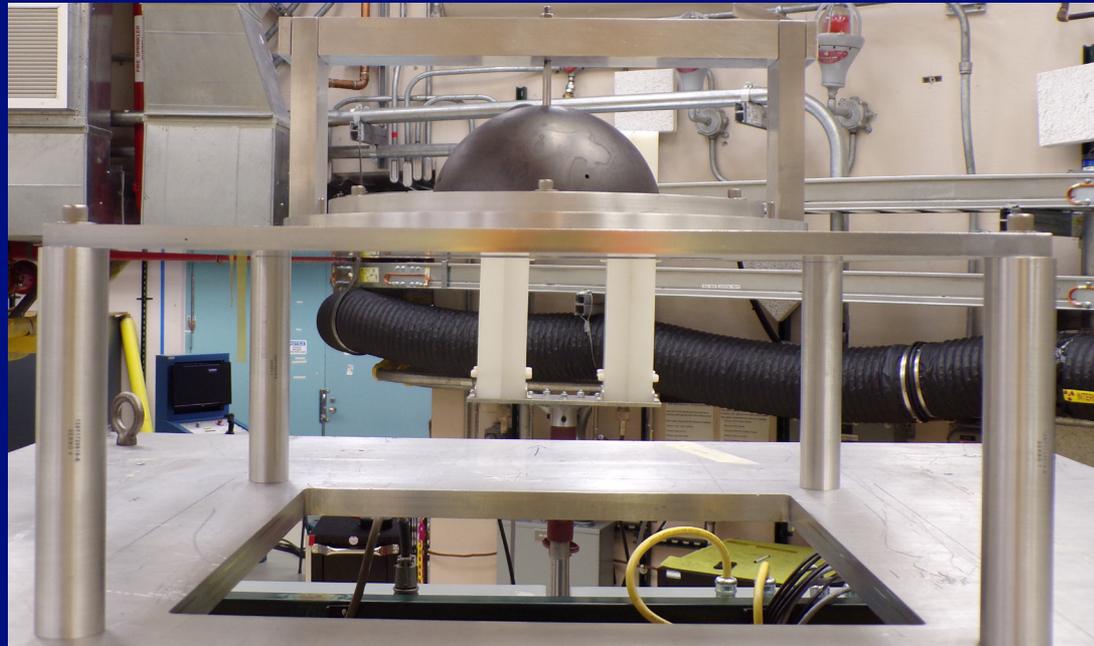
- Critical configurations differed by thickness of aluminum spacer separating stacks and substitution of an inner HEU shell



Configuration	Spacer Thickness [in (cm)]	Total HEU Mass (kg)
8	0.060 (0.1524)	60.612
9	0.0243 (0.061807)	60.438

Configurations

- Configuration 8 measured with and without additional detector equipment
 - Allows experimental bias calculation (36 pcm)

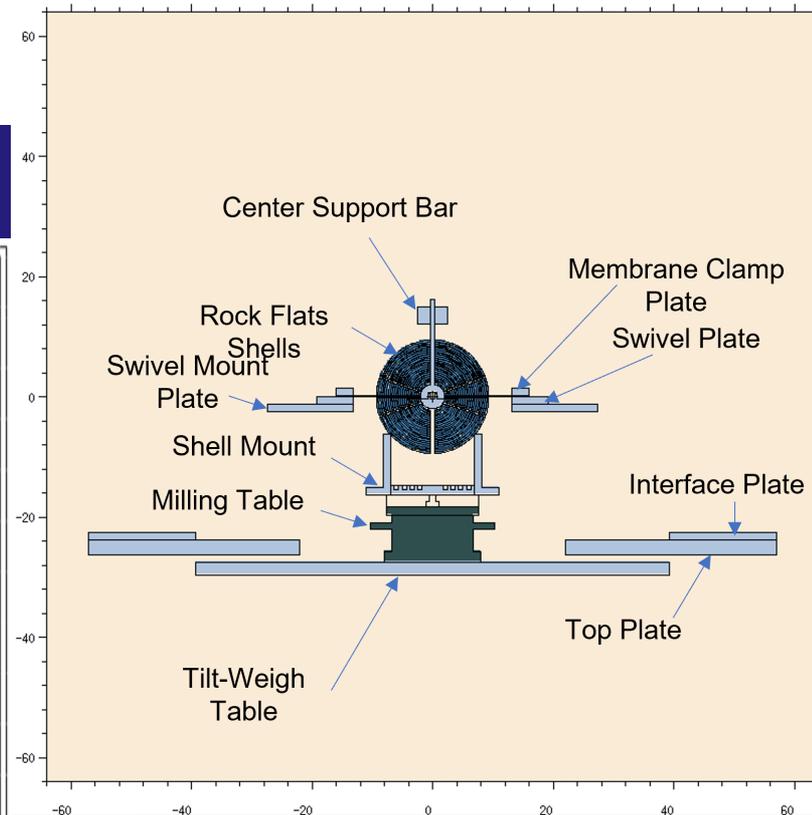


ICSBEP Detailed Model

- Calculations used MCNP 6.2.1 with ENDF/VIII.0 cross sections

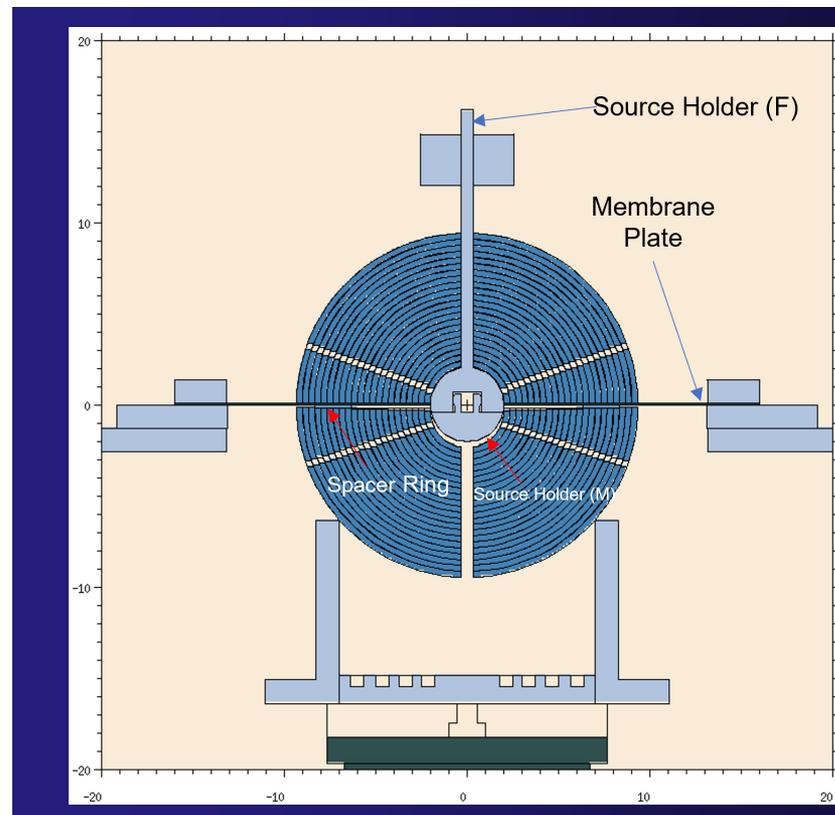
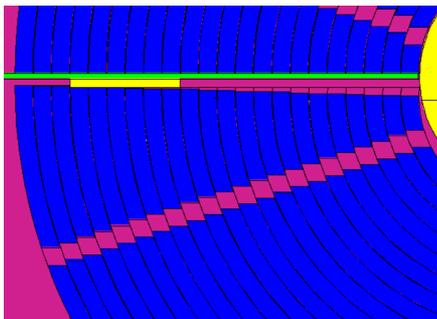
3,500 generations, 5×10^5 neutrons per generation for 1 pcm statistical uncertainty

Simplification	$\Delta k_{eff} \pm 1\sigma_{MC}$
Removal of Additional Detectors	-0.00036 ± 0.00013
Shell Mount Simplification	-0.00019 ± 0.00001
Removal of Rocky Flats Impurities	0.00001 ± 0.00001
Milling Table Simplification	-0.00001 ± 0.00001
Removal of Flattop	$+0.00002 \pm 0.00001$
Removal of Screws, Pins, and Counterbores	-0.00002 ± 0.00001
Removal of Planet Structural Components	-0.00035 ± 0.00001
Removal of Concrete and Crane	-0.00063 ± 0.00001
Temperature Configuration 8	$+0.00022$
Temperature Configuration 9	$+0.00023$
Total Configuration 8	-0.00131 ± 0.00013
Total Configuration 9	-0.00130 ± 0.00013



ICSBEP Detailed Model

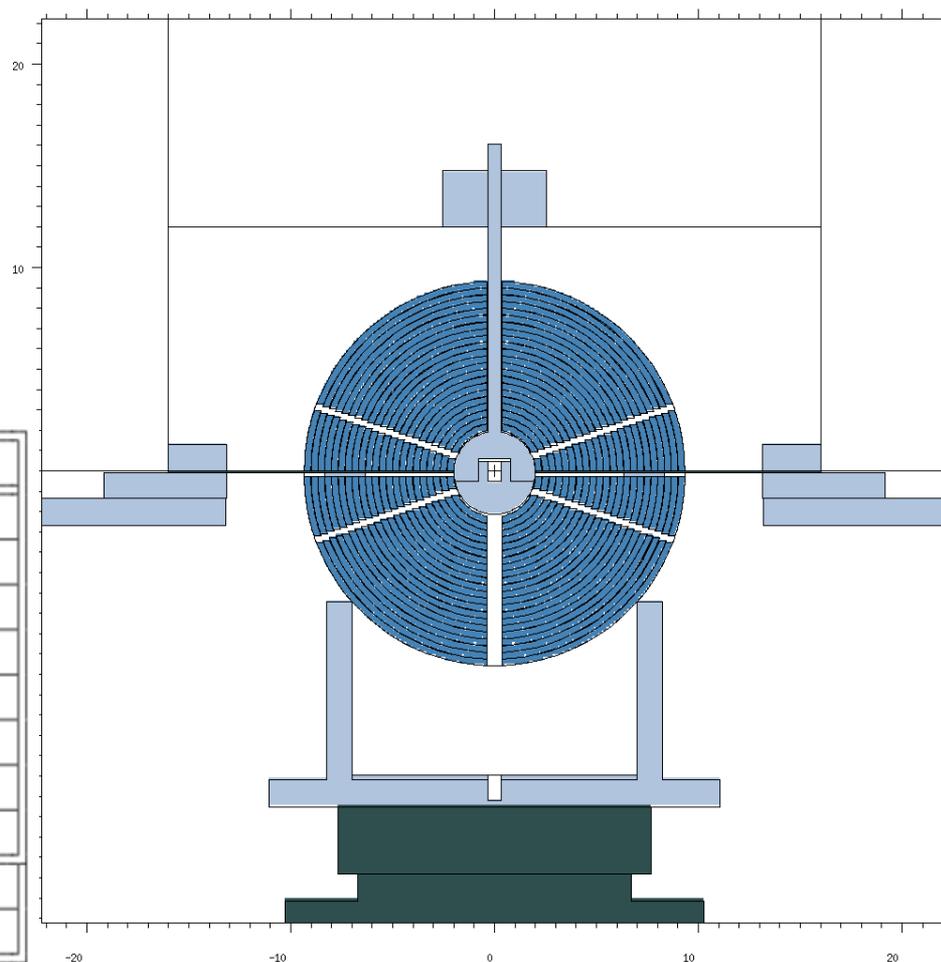
- Includes pry holes within HEU shells
- Also has nesting of bottom HEU shells
 - As opposed to shells being concentric
- Unable to remove pry holes or homogenize HEU to any extent (bias)



ICSBEP Simplified Model

- Further simplifications include removal of aluminum impurities, further source holder, shell mount and milling table geometry, and concentric HEU shells

Simplification	$\Delta k_{eff} \pm 1\sigma_{MC}$
Previous Simplifications Configuration 8	-0.00131 ± 0.00013
Previous Simplifications Configuration 9	-0.00130 ± 0.00020
Removal of Air	-0.00013 ± 0.00001
Removal of Aluminum Impurities	$+0.00002 \pm 0.00001$
Removal of Milling Table Keyways	$+0.00029 \pm 0.00001$
Removal of Shell Mount Channels	$+0.00011 \pm 0.00001$
Removal of Lower Rocky Flats Offsets	$+0.00018 \pm 0.00001$
Source Holder Simplification	-0.00000 ± 0.00001
Total Configuration 8	-0.00084 ± 0.00013
Total Configuration 9	-0.00083 ± 0.00020



Uncertainty Analysis

- Includes critical measurement, masses, compositions, positioning, dimensions, and temperature
- Mass and composition utilize adjoint-based KSEN capability
- Some analyses still ongoing at time of writing
- **HMF001 Uncertainty ± 0.00100**

Category	Total u_k C8	Total u_k C9
Critical Measurement	+0.00013	+0.00020
Mass	± 0.00006	± 0.00006
Composition	± 0.00059	± 0.00059
Positioning	± 0.00022	± 0.00022
Dimensions	± 0.00077	± 0.00069
Temperature	± 0.00008	± 0.00008
Total So Far	± 0.00101	± 0.00100

J. Favorite, et al, "Adjoint-Based Sensitivity and Uncertainty Analysis for Density and Composition: A User's Guide," Nucl. Sci. & Eng., 185, 384 (2017).

Current Results

- Inference of k_{eff} from reactor period based on Lady Godiva data
 - Measurements of Rossi- α still undergoing analysis
 - Simulations based on ENDF-VIII.0

Configuration	Average Reactor Period (s)	Inferred k_{eff}	Benchmark k_{eff}	Detailed Model k_{eff}	C-E (pcm)
C8	16.1 ± 1.8	1.00203	1.00072	1.00033	-39
C9	13.5 ± 2.2	1.00221	1.00091	1.00021	-70

Configuration	Average Reactor Period (s)	Inferred k_{eff}	Benchmark k_{eff}	Simplified Model k_{eff}	C-E (pcm)
C8	16.1 ± 1.8	1.00203	1.00119	1.00029	-90
C9	13.5 ± 2.2	1.00221	1.00138	1.00028	-110

Conclusions

- **Work is on track for submission to April 2023 ICSBEP review group meeting**
- **Document has been submitted to internal and external reviewers and ICSBEP chair**
- **Current results show promise for a low uncertainty evaluation**
- **Future work:**
 - ICSBEP comment resolution
 - Subcritical benchmark evaluation of the NoMAD measurements
 - Further analysis and potential benchmark evaluation of organic scintillator measurements

Acknowledgements

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