Nuclear Data Evaluation and Testing for Nuclear Criticality Safety Applications

March 27, 2019

Alex Shaw and Farzad Rahnema
Georgia Institute of Technology

NCSP 2019 Technical Program Review
PANTEX
March 26-27, 2019

Outline

- Introduction
- Benchmark Identification and Modeling
- Results
- Summary and conclusion
- Acknowledgement

Objective

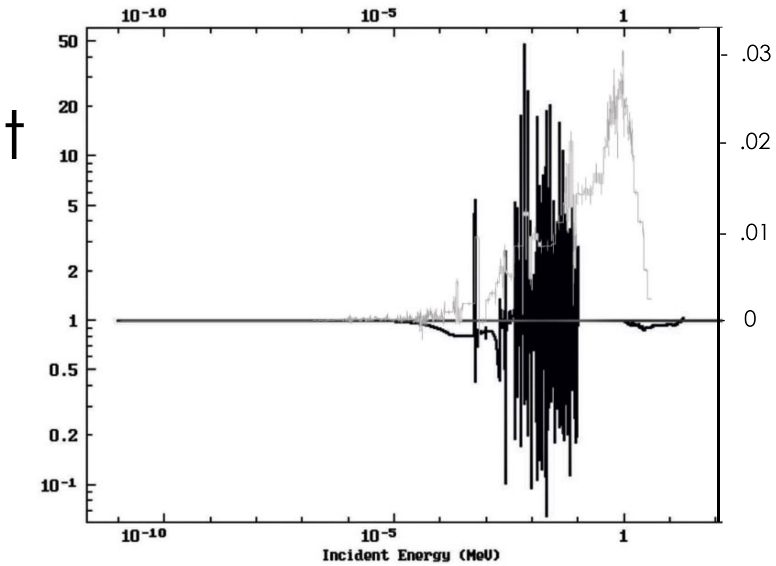
- Identify benchmark experiments for cross section evaluation for NCS purposes, with specified materials of interest
- Model selected benchmarks in CE SCALE and MCNP, obtaining criticality results for comparison of cross section libraries ENDF 7.1 and ENDF 8
- Gauge and test recent nuclear data evaluations, providing feedback on performance

Introduction

- Benchmark identification is done in reference to the NCSP 5 year plan, with materials of interest recently completed evaluations
  - Ca; Co-59; Cu-63, 65; Ni-58, 60; W-182,183,184,186
  - Lucite, Polyethylene, Beryllium, Beryllium Oxide, Crystal Graphite, Reactor Graphite, Silicon Carbide, Silicon Dioxide, Uranium Dioxide, Uranium Nitride, Hexagonal Ice, Yttrium Hydride
- Criticality sensitivities are used to find relevant benchmarks, as sensitive benchmarks will be susceptible to change, if at all
- Takes into account: geometry of material, material number density, flux spectrum of benchmark
- Provides comprehensive view of benchmark dependence on XS

Identification and Modeling

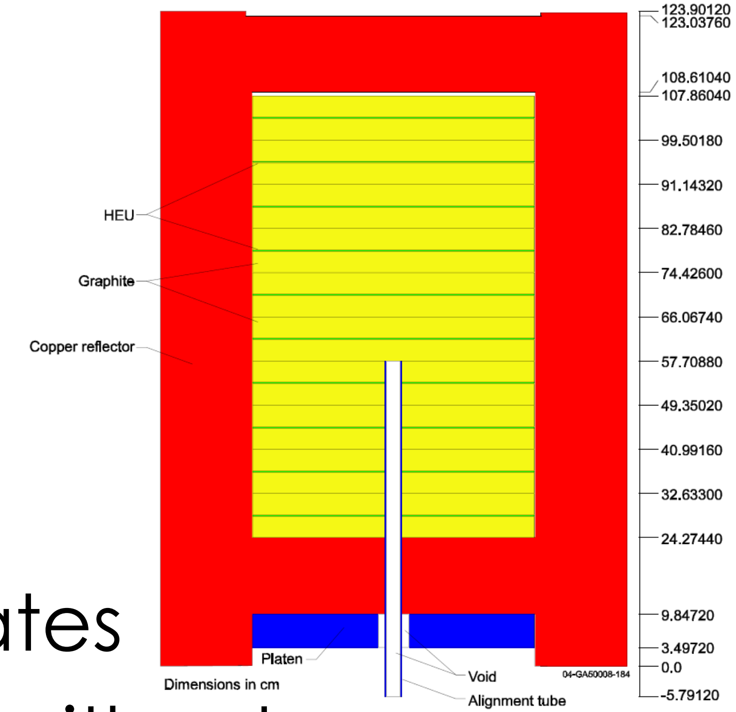
- For isotope sensitivity, direct use of DICE(included in ICSBEP Handbook)
- For XS updates, direct ENDF data
- Alignment of sensitivity and XS change for greatest expected change
- Models constructed from Section 3 of ICSBEP benchmark evaluation
- Materials listed in natural abundance are decomposed to constituent isotopes, as ACE ENDF 8 libraries are not available as natural



HMI-006 Cu-63 Scattering Sensitivity(Grey)
Cu-63 Scattering XS, Ratio ENDF8/ENDF7(Black)

HEU Metal Intermediate-006

- Identified for high sensitivity to Copper XS
- Of further interest is presence of Graphite
- HEU metal discs(green) interspersed with Graphite discs(yellow), surrounded by Copper reflector(red)
- 4 cases; decreasing number of Graphite plates
- Uniform disc heights, homogenous material without impurities



HEU Metal Intermediate-006

- Both codes use CE data; difference in Δk is <3σ as expected
- For this benchmark, Cases 1,2,4 trend closer to criticality with ENDF 8
- Benchmark Model Uncertainty: 80-90 pcm
  (Experimental Uncertainty + Simplification bias)

KENO

Case	ENDF/B-VII.1(±10)*	Case	ENDF/B-VIII(±10)*	Δk(pcm)
1	0.993069	1	0.995474	241±14
2	0.997005	2	1.000188	318±14
3	1.000661	3	1.002886	222±14
4	1.005685	4	1.003687	-199±14

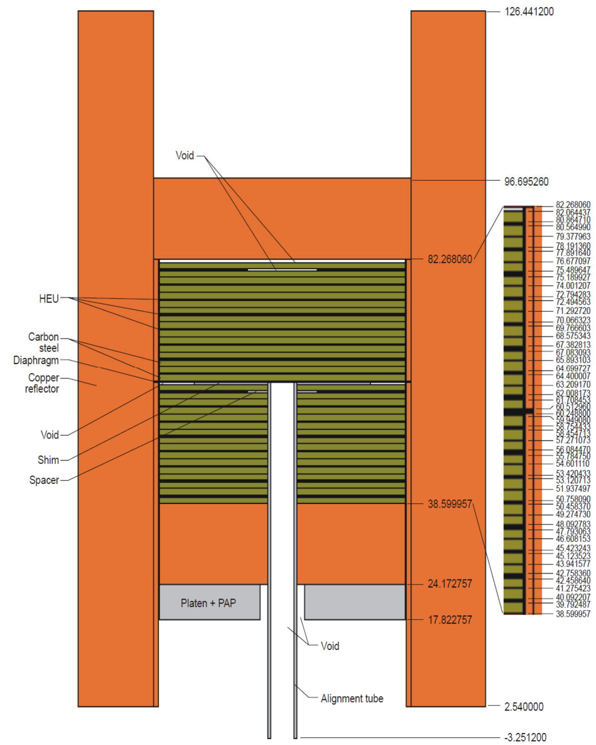
MCNP

Case	ENDF/B-VII.1(±4)*	Case	ENDF/B-VIII(±4)*	Δk(pcm)
1	0.99294	1	0.99584	290±6
2	0.99689	2	1.00027	338±6
3	1.00076	3	1.00325	249±6
4	1.0073	4	1.00537	-193±6

*All Uncertainty Values Expressed in pcm

HEU Metal Fast-072

- Identified for high sensitivity to Copper XS
- Of further interest is presence of HDPE(Case 3)
- HEU metal discs(black) interspersed with Graphite discs(green), surrounded by Copper reflector(orange)
- 3 cases; Case 2 reduced reflector height, Case 3 added HDPE and reduced core height
- Nonuniform disc heights, heterogenous material with impurities



HEU Metal Fast-072

- All 3 cases trend closer toward criticality
- Case 1&2 significantly so
- Benchmark Model Uncertainty:

  Cases 1&2: 240 pcm

  Case 3: 690 pcm

KENO

Case	ENDF/B-VII.1(±10)*	Case	ENDF/B-VIII(±10)*	Δk(pcm)
1	1.008343	1	1.00412	-422±14
2	1.009737	2	1.00571	-403±14
3	1.012348	3	1.011367	-98±14

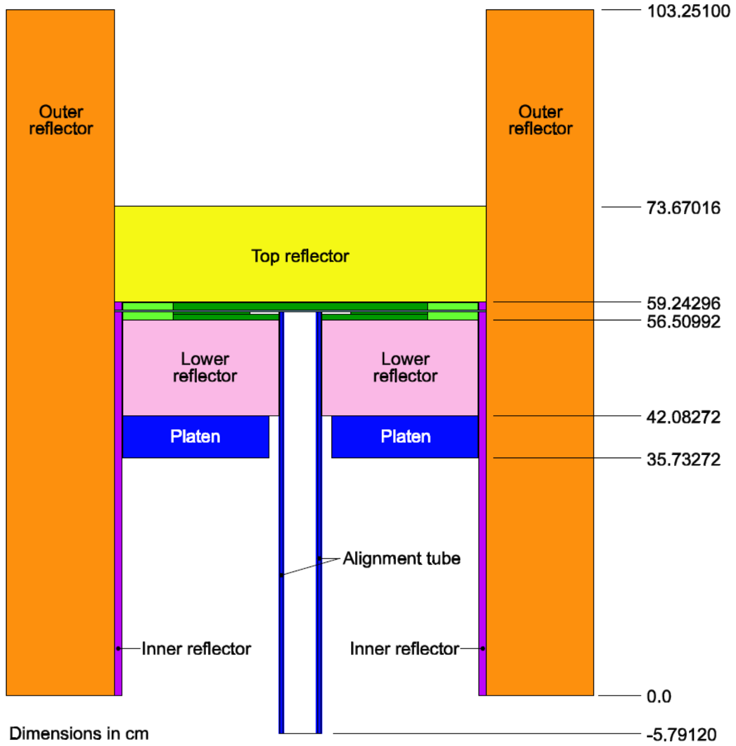
MCNP

Case	ENDF/B-VII.1(±3)*	Case	ENDF/B-VIII(±3)*	Δk(pcm)
1	1.00853	1	1.00397	-456±4
2	1.00955	2	1.00481	-474±4
3	1.01236	3	1.01146	-90±4

*All Uncertainty Values Expressed in pcm

HEU Metal Fast-073

- Identified for high sensitivity to Copper XS
- HEU metal discs(dark green) surrounded by HEU metal rings(light green), surrounded by Copper reflector(yellow, orange, pink)
- No impurities, individual fuel segments homogenous. Reflector material split into individually homogenous Top, Lower, Inner(Side), Outer(Side)



HEU Metal Fast-073

- ENDF 8 significantly improves results- closer to criticality
- Benchmark Model Uncertainty:
  160 pcm

KENO

Case	ENDF/B-VII.1(±10)*	Case	ENDF/B-VIII(±10)*	Δk(pcm)
1	1.011515	1	1.00334	-818±14

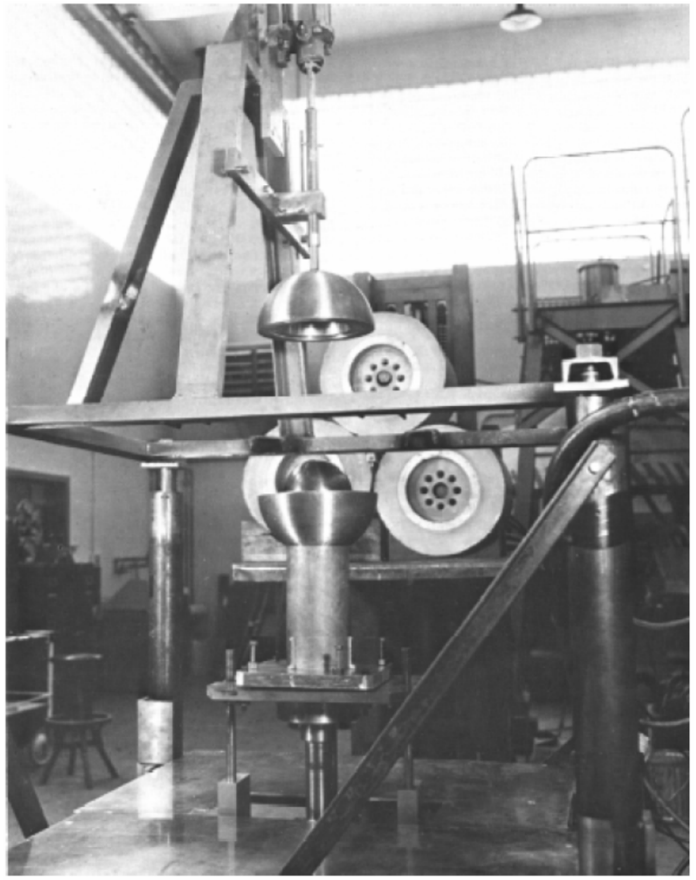
MCNP

Case	ENDF/B-VII.1(±3)*	Case	ENDF/B-VIII(±3)*	Δk(pcm)
1	1.01134	1	1.00284	-850±4

*All Uncertainty Values Expressed in pcm

HEU Metal Fast-085

- Concentric spheres of HEU and:
  1. Copper*
  2. Copper*
  3. Cast iron
  4. Nickel-Copper-Zinc-alloy*
  5. Thorium
  6. Tungsten alloy*



*Contains Materials of Interest

HEU Metal Fast-085

- Cases 2, 3, 5, and 6 improve with ENDF 8
- While Case 3&5 are not of explicit interest, exhibit XS improvement
- Mixed results for those of interest; 1 instance of Copper improves, the other does not. Ni-Cu alloy worse as well
- Benchmark Model Uncertainty: 300 pcm

KENO

Case	ENDF/B-VII.1(±10)*	Case	ENDF/B-VIII(±10)*	Δk(pcm)
1	1.000285	1	0.994822	-546±14
2	1.004361	2	0.996746	-762±14
3	0.995251	3	0.998475	322±14
4	0.999946	4	0.995283	-466±14
5	1.000582	5	1.000428	-15±14
6	1.00577	6	1.003567	-220±14

MCNP

Case	ENDF/B-VII.1(±3)*	Case	ENDF/B-VIII(±3)*	Δk(pcm)
1	1.00006	1	0.99462	-544±4
2	1.00436	2	0.99677	-759±4
3	0.99609	3	0.99854	245±4
4	0.9998	4	0.99518	-462±4
5	1.00041	5	1.00035	-6±4
6	1.00606	6	1.0035	-256±4

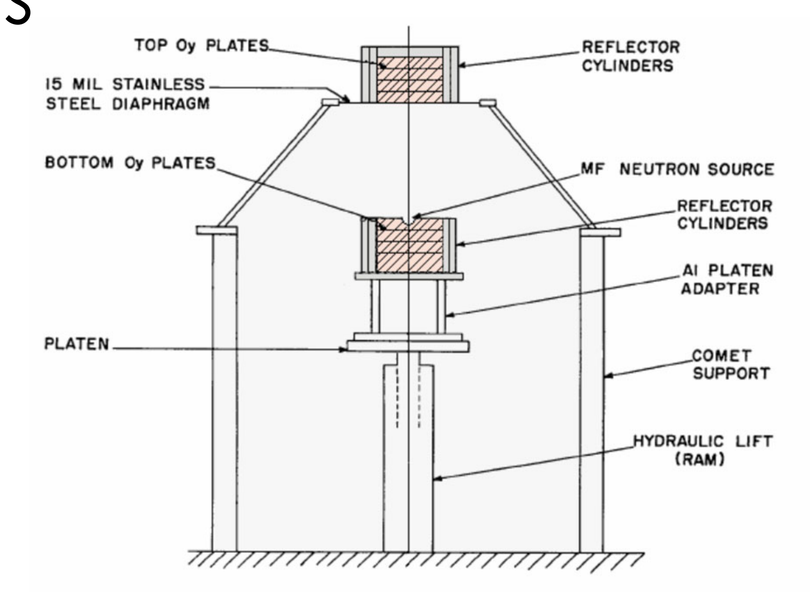
*All Uncertainty Values Expressed in pcm

Summary and conclusions

- 11 Benchmark cases with Copper, of which 8 show improvement, 6 with significant improvement
- 4 Benchmark cases with Graphite, of which 3 show significant improvement
- 1 with Polyethylene, Tungsten, Nickel, with respective improvement, improvement, and worsening
- While still too early to draw conclusions, 11 out of 14 total evaluated cases showed improvement over ENDF 7.1 XS

Modeling in Progress: HMF-084

- Series of nested HEU and reflector cylinders
- Impurities and structural material ignored
- Copper, Nickel, Cobalt, Poly, Tungsten



Future Modeling

- HST-007; Ca
- PMF-005, -013, -014, -040; All Cu/Ni
- HMF-003, -049, -050; All W
- Search for more evaluations with thermal scattering compounds

Acknowledgement

- Acknowledgement:
  - This work was supported by US Department of Energy (DOE), Nuclear Criticality Safety Program (NCSP) funded and managed by the National Nuclear Security Administration (NNSA) for DOE.
  - Assistance provided by Drs. Doug Bowen, Andrew Holcomb, and BJ Marshall during the course of this work is greatly appreciated

Questions?