Whisper Sensitivity Study of the NMIS ATR Fuel Storage Racks

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Cadmium Plywood Shelves

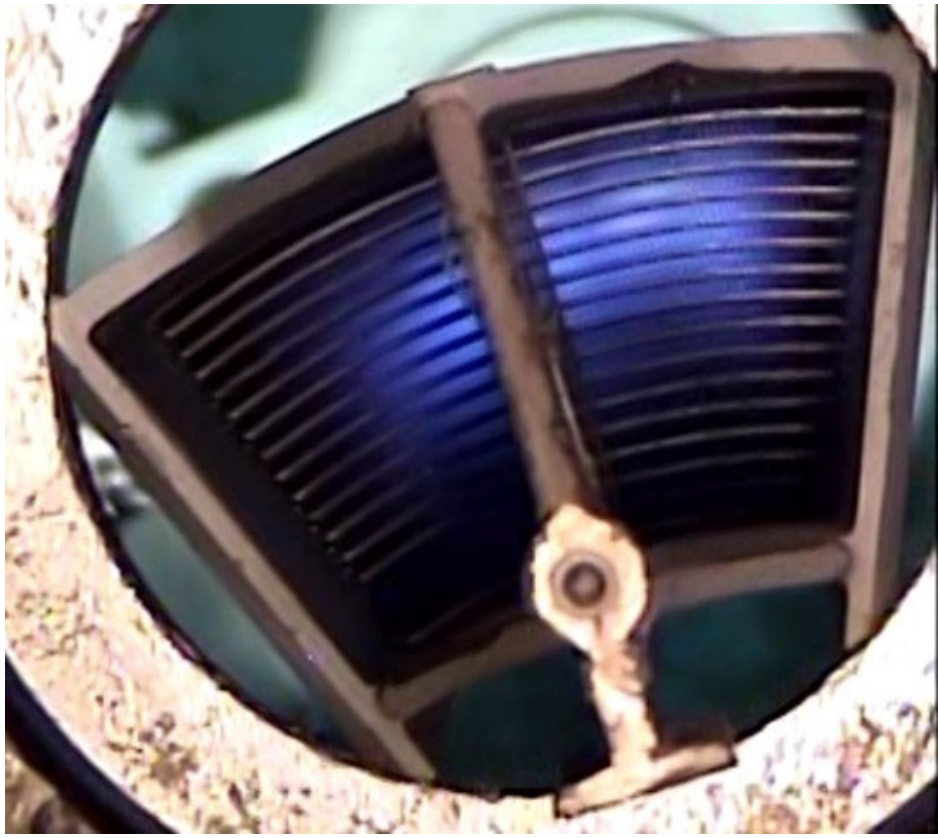
- Shelves are constructed of plywood with two sheets of 0.010” cadmium.
- Significant fire hazard.
- Cadmium is toxic. A fire with cadmium is the bounding accident in the SAR.
- The amount of Cd was underestimated resulting in a long standing PIZA of ~10 yrs.

AMMC Shelves

- Stainless steel corrugated sheet to make positions for ATR fuel elements.
- Aluminum-boron carbide metal matrix neutron absorber. 40 mg B^{10}/cm^2
- Aluminum structural cross bars.

NMIS Racks Accident Scenario

- Because of the fire loading and value of the ATR fuel in NMIS, there is a halon fire protection system, a wet pipe fire protection system, and no restriction on manual firefighting.
- The bounding accident scenario for criticality safety is water getting between the ATR fuel plates with no water or mist between elements.
- Because of the high surface area to volume of the ATR fuel elements they tend to hold water and would not drain immediately.



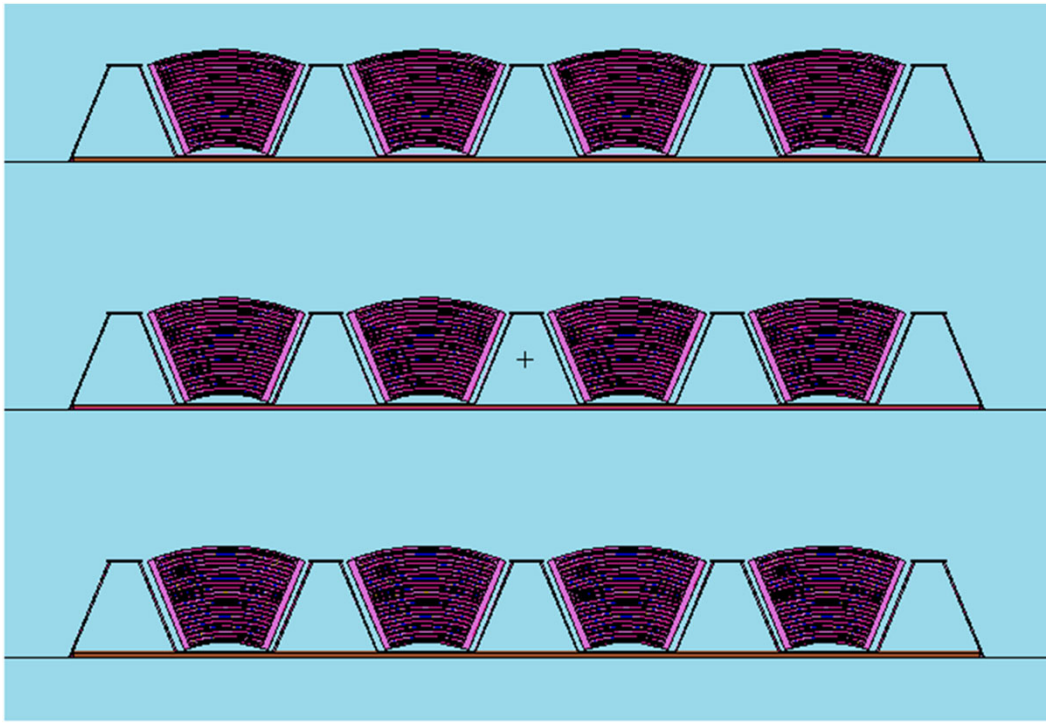
Whisper

- whisper_mcnp.pl input

  takes an MCNP input deck and adds KSEN card then runs MCNP to calculate sensitivities.

- whisper_usl.pl

  runs Whisper to compare the sensitivity profile to the sensitivity profiles of over 1100 benchmarks and calculates a usl



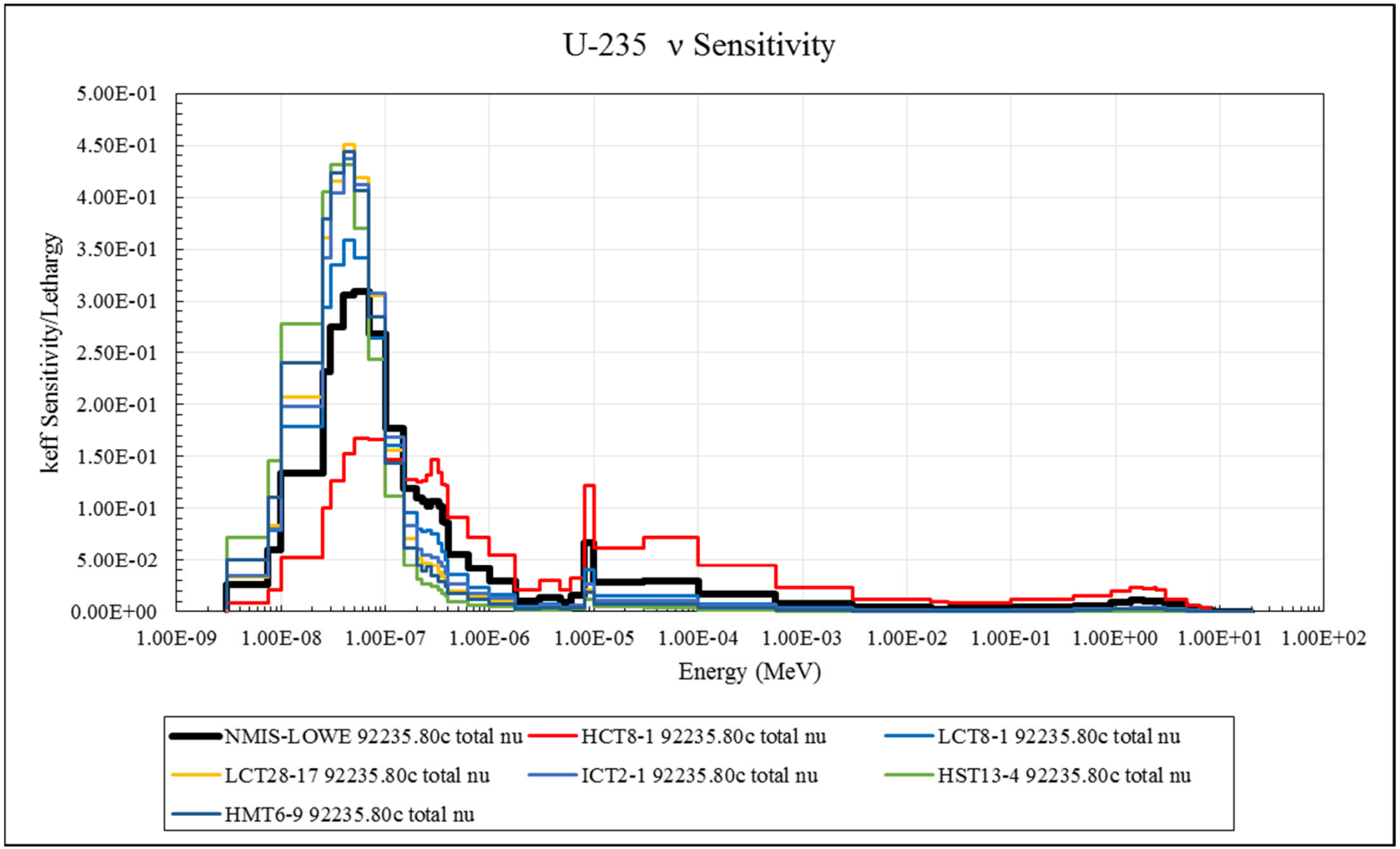
Whisper Output

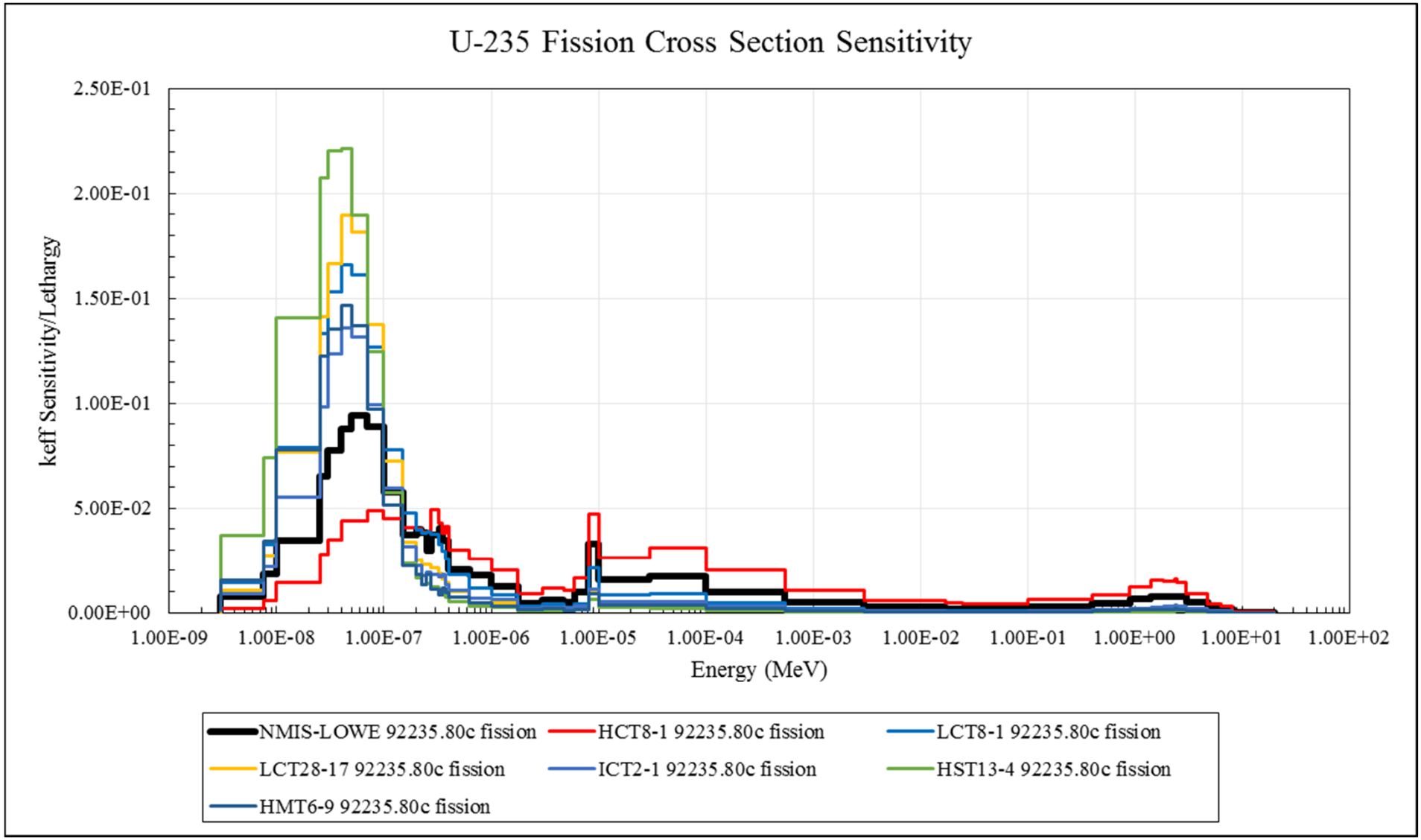
- USL of 0.97347
- 102 benchmarks
- Benchmarks that could be chosen from engineering judgement.
- The interesting part is the comparison of the sensitivity profiles

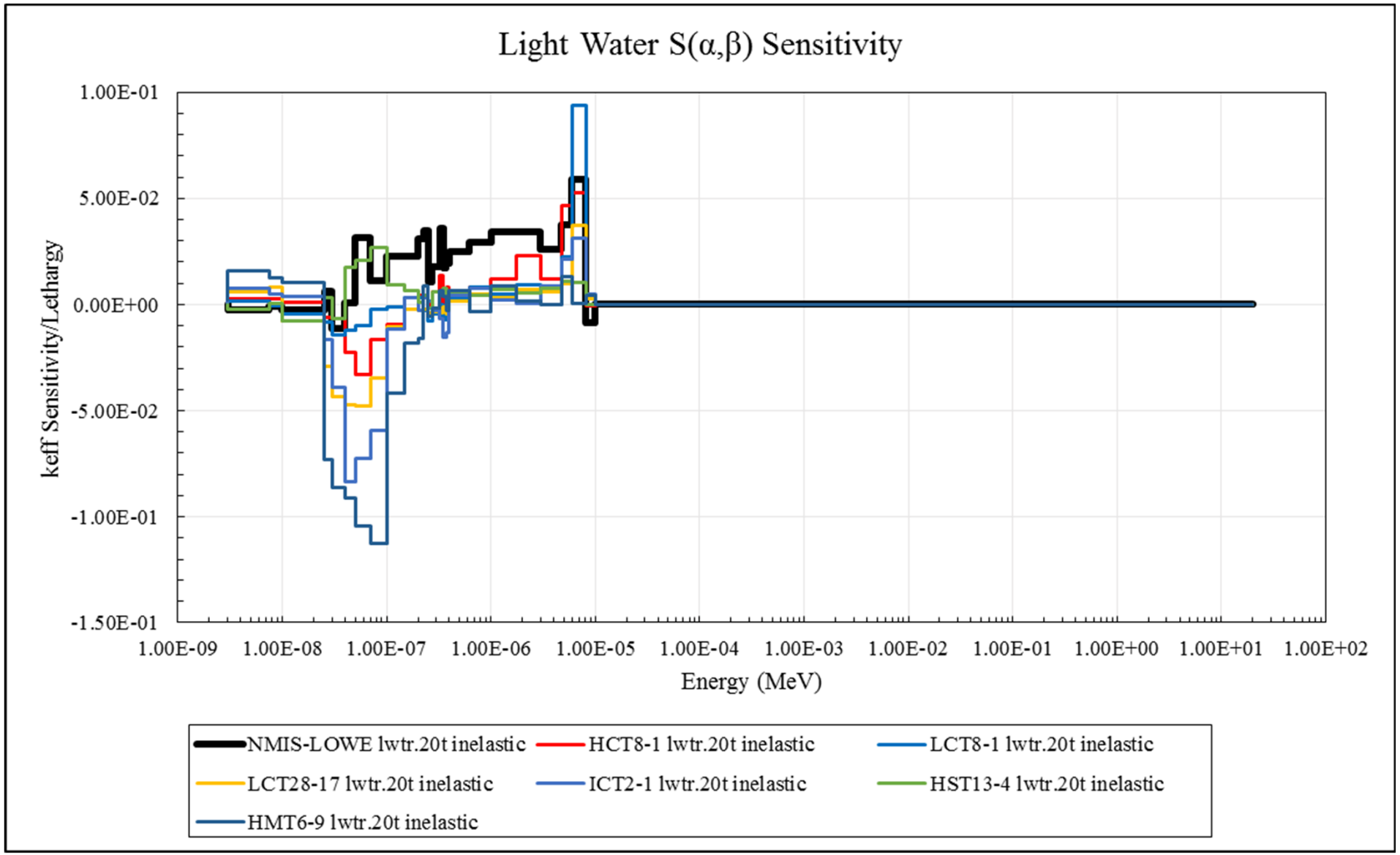
application	calc margin	data unc (1-sigma)	baseline USL	k(calc) > USL
ALEU-0.110inAlB4C_Sheet_30wt%-025wdens-S	0.01927	0.00087	0.97347	-0.23506

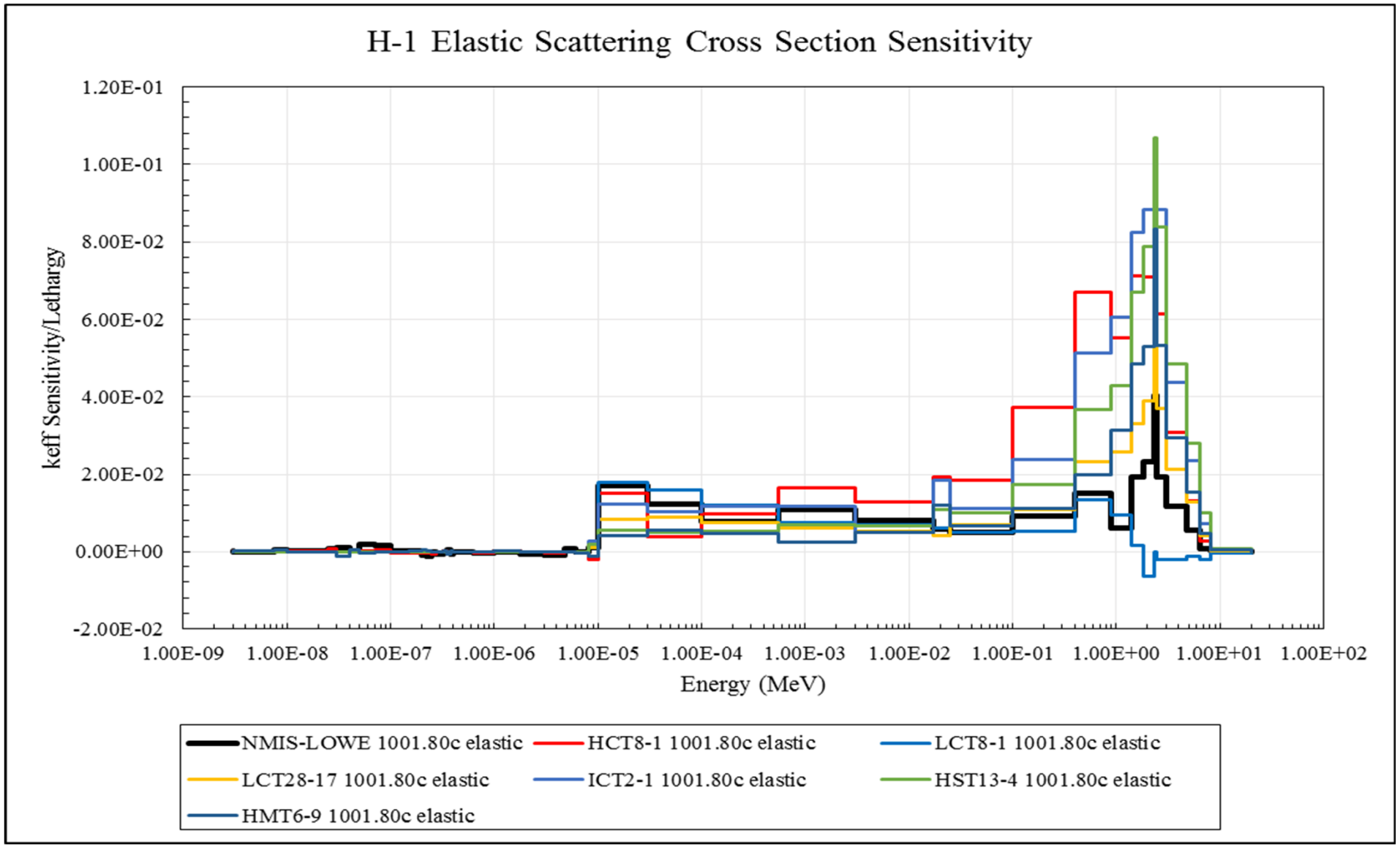
```
Benchmark population   =  102
Population weight      =  37.02460
Maximum similarity     =   0.87976

Bias                   =   0.01132
Bias uncertainty       =   0.00795
Nuc Data uncert margin =   0.00087
Software/method margin =   0.00500
Non-coverage penalty   =   0.00000
```

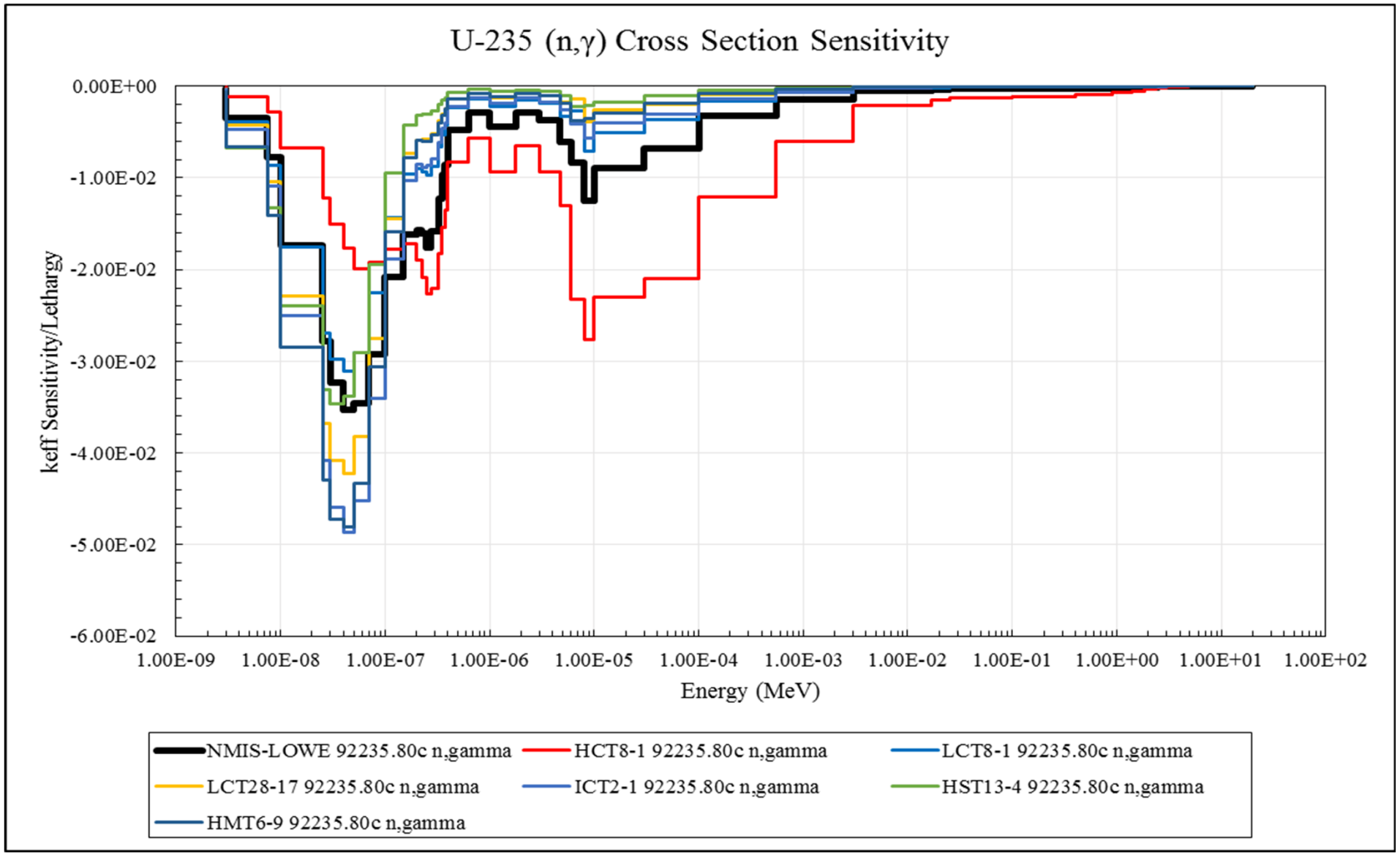
benchmark	ck	weight
leu-comp-therm-028-017.i	0.8798	1.0000
leu-comp-therm-005-004.i	0.8789	0.9909
leu-comp-therm-028-020.i	0.8705	0.8988
leu-comp-therm-028-018.i	0.8704	0.8977
leu-comp-therm-005-003.i	0.8698	0.8920
leu-comp-therm-028-012.i	0.8600	0.7846
leu-comp-therm-028-014.i	0.8588	0.7722
leu-comp-therm-028-019.i	0.8573	0.7555
leu-comp-therm-011-007.i	0.8558	0.7393
leu-comp-therm-011-003.i	0.8553	0.7335
leu-comp-therm-028-016.i	0.8539	0.7190
ieu-comp-therm-002-003.i	0.8525	0.7037
leu-comp-therm-011-009.i	0.8521	0.6994
leu-comp-therm-017-010.i	0.8444	0.6155
leu-comp-therm-011-002.i	0.8429	0.5989
leu-sol-therm-020-004.i	0.8411	0.5801
leu-comp-therm-010-009.i	0.8406	0.5746
leu-comp-therm-010-005.i	0.8403	0.5706
leu-comp-therm-011-015.i	0.8393	0.5605
leu-sol-therm-002-001.i	0.8379	0.5452
leu-comp-therm-028-015.i	0.8374	0.5394
leu-comp-therm-017-011.i	0.8356	0.5203
leu-comp-therm-010-006.i	0.8339	0.5011
leu-comp-therm-008-008.i	0.8339	0.5008
leu-sol-therm-020-003.i	0.8337	0.4989
leu-sol-therm-021-004.i	0.8334	0.4957
leu-comp-therm-017-012.i	0.8322	0.4831
leu-comp-therm-010-010.i	0.8320	0.4805
leu-comp-therm-022-007.i	0.8312	0.4718
leu-comp-therm-010-011.i	0.8299	0.4578
leu-comp-therm-007-004.i	0.8297	0.4556
leu-comp-therm-028-013.i	0.8295	0.4530
leu-comp-therm-028-011.i	0.8277	0.4344
leu-comp-therm-017-013.i	0.8274	0.4305
leu-comp-therm-017-004.i	0.8274	0.4303
leu-comp-therm-028-009.i	0.8267	0.4230
leu-comp-therm-017-008.i	0.8265	0.4208
leu-comp-therm-022-006.i	0.8263	0.4188
leu-comp-therm-028-004.i	0.8261	0.4160
leu-sol-therm-021-003.i	0.8259	0.4146
leu-comp-therm-017-006.i	0.8254	0.4085
leu-comp-therm-017-007.i	0.8239	0.3928
leu-comp-therm-017-014.i	0.8237	0.3901
leu-comp-therm-017-005.i	0.8230	0.3823


U-235 ν Sensitivity
keff Sensitivity/Lethargy
5.00E-01
4.50E-01
4.00E-01
3.50E-01
3.00E-01
2.50E-01
2.00E-01
1.50E-01
1.00E-01
5.00E-02
0.00E+00
1.00E-09
1.00E-08
1.00E-07
1.00E-06
1.00E-05
1.00E-04
1.00E-03
1.00E-02
1.00E-01
1.00E+00
1.00E+01
1.00E+02
Energy (MeV)
NMIS-LOWE 92235.80c total nu
HCT8-1 92235.80c total nu
LCT8-1 92235.80c total nu
LCT28-17 92235.80c total nu
ICT2-1 92235.80c total nu
HST13-4 92235.80c total nu
HMT6-9 92235.80c total nu


U-235 Fission Cross Section Sensitivity
2.50E-01
2.00E-01
1.50E-01
1.00E-01
5.00E-02
0.00E+00
keff Sensitivity/Lethargy
1.00E-09
1.00E-08
1.00E-07
1.00E-06
1.00E-05
1.00E-04
1.00E-03
1.00E-02
1.00E-01
1.00E+00
1.00E+01
1.00E+02
Energy (MeV)
NMIS-LOWE 92235.80c fission
HCT8-1 92235.80c fission
LCT8-1 92235.80c fission
LCT28-17 92235.80c fission
ICT2-1 92235.80c fission
HST13-4 92235.80c fission
HMT6-9 92235.80c fission


Light Water S(α,β) Sensitivity
1.00E-01
5.00E-02
0.00E+00
-5.00E-02
-1.00E-01
-1.50E-01
keff Sensitivity/Lethargy
1.00E-09
1.00E-08
1.00E-07
1.00E-06
1.00E-05
1.00E-04
1.00E-03
1.00E-02
1.00E-01
1.00E+00
1.00E+01
1.00E+02
Energy (MeV)
NMIS-LOWE lwtr.20t inelastic
HCT8-1 lwtr.20t inelastic
LCT8-1 lwtr.20t inelastic
LCT28-17 lwtr.20t inelastic
ICT2-1 lwtr.20t inelastic
HST13-4 lwtr.20t inelastic
HMT6-9 lwtr.20t inelastic

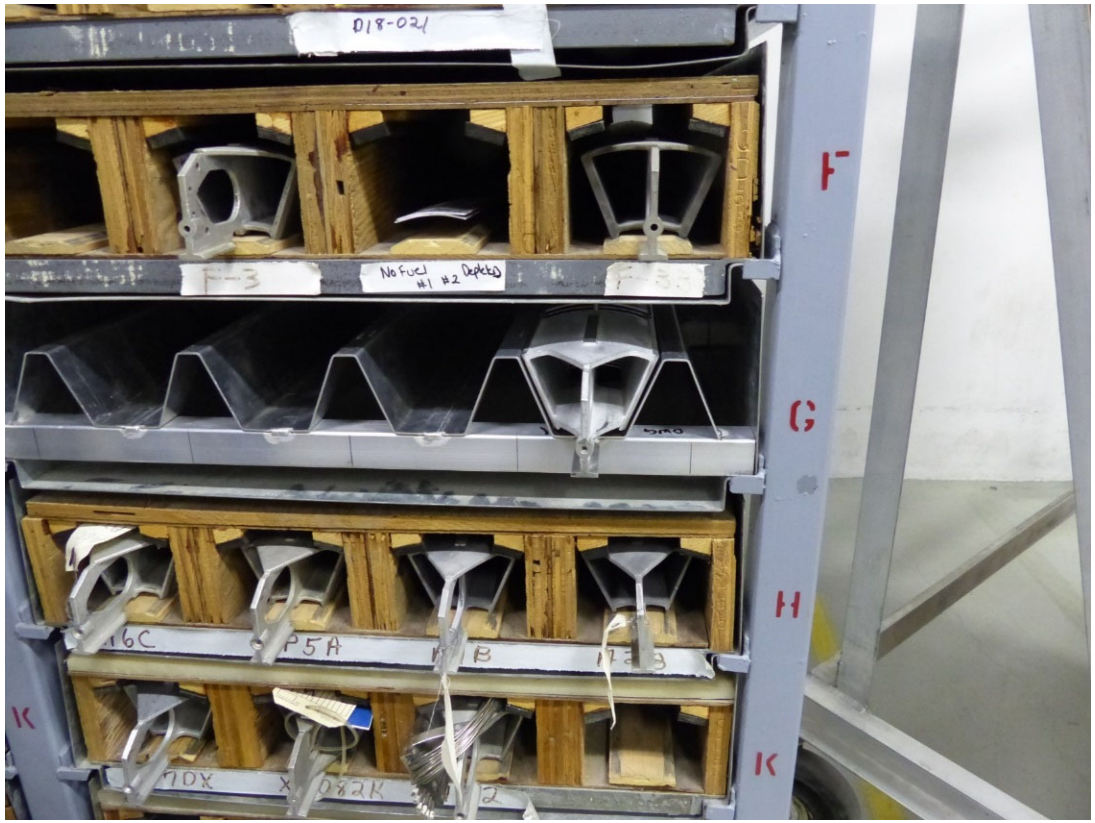

H-1 Elastic Scattering Cross Section Sensitivity
keff Sensitivity/Lethargy
1.20E-01
1.00E-01
8.00E-02
6.00E-02
4.00E-02
2.00E-02
0.00E+00
-2.00E-02
1.00E-09
1.00E-08
1.00E-07
1.00E-06
1.00E-05
1.00E-04
1.00E-03
1.00E-02
1.00E-01
1.00E+00
1.00E+01
1.00E+02
Energy (MeV)
NMIS-LOWE 1001.80c elastic
HCT8-1 1001.80c elastic
LCT8-1 1001.80c elastic
LCT28-17 1001.80c elastic
ICT2-1 1001.80c elastic
HST13-4 1001.80c elastic
HMT6-9 1001.80c elastic


U-235 (n,γ) Cross Section Sensitivity
keff Sensitivity/Lethargy
0.00E+00
-1.00E-02
-2.00E-02
-3.00E-02
-4.00E-02
-5.00E-02
-6.00E-02
1.00E-09
1.00E-08
1.00E-07
1.00E-06
1.00E-05
1.00E-04
1.00E-03
1.00E-02
1.00E-01
1.00E+00
1.00E+01
1.00E+02
Energy (MeV)
NMIS-LOWE 92235.80c n,gamma
HCT8-1 92235.80c n,gamma
LCT8-1 92235.80c n,gamma
LCT28-17 92235.80c n,gamma
ICT2-1 92235.80c n,gamma
HST13-4 92235.80c n,gamma
HMT6-9 92235.80c n,gamma

Whisper Summary

- Whisper suggested benchmarks which sensitivity profiles matched very well with the targeted application.
- These benchmarks also matched EALF and parameters that would be chosen by engineering judgement such as enrichment and moderator type.
- The application of Whisper gives greater confidence in the validation.

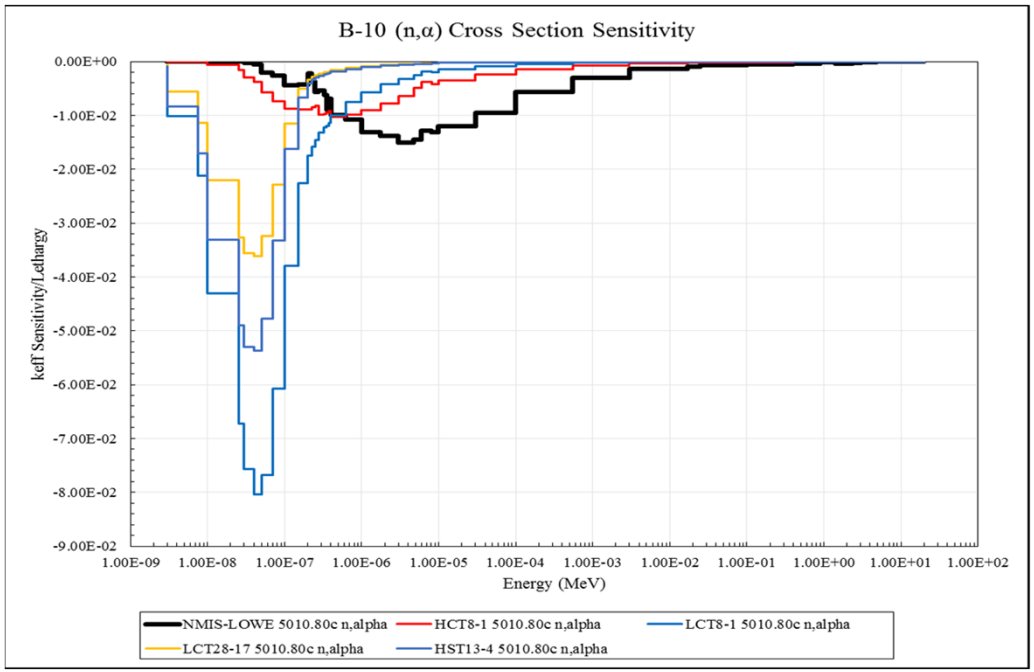
- What about boron?

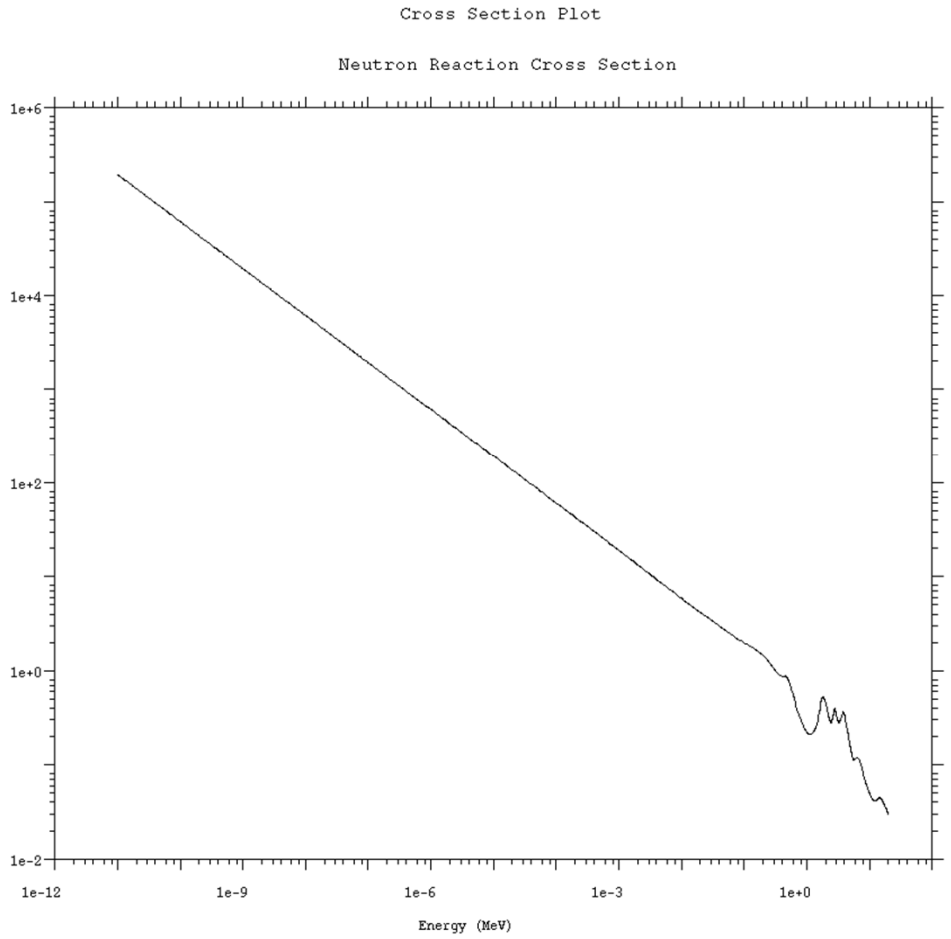


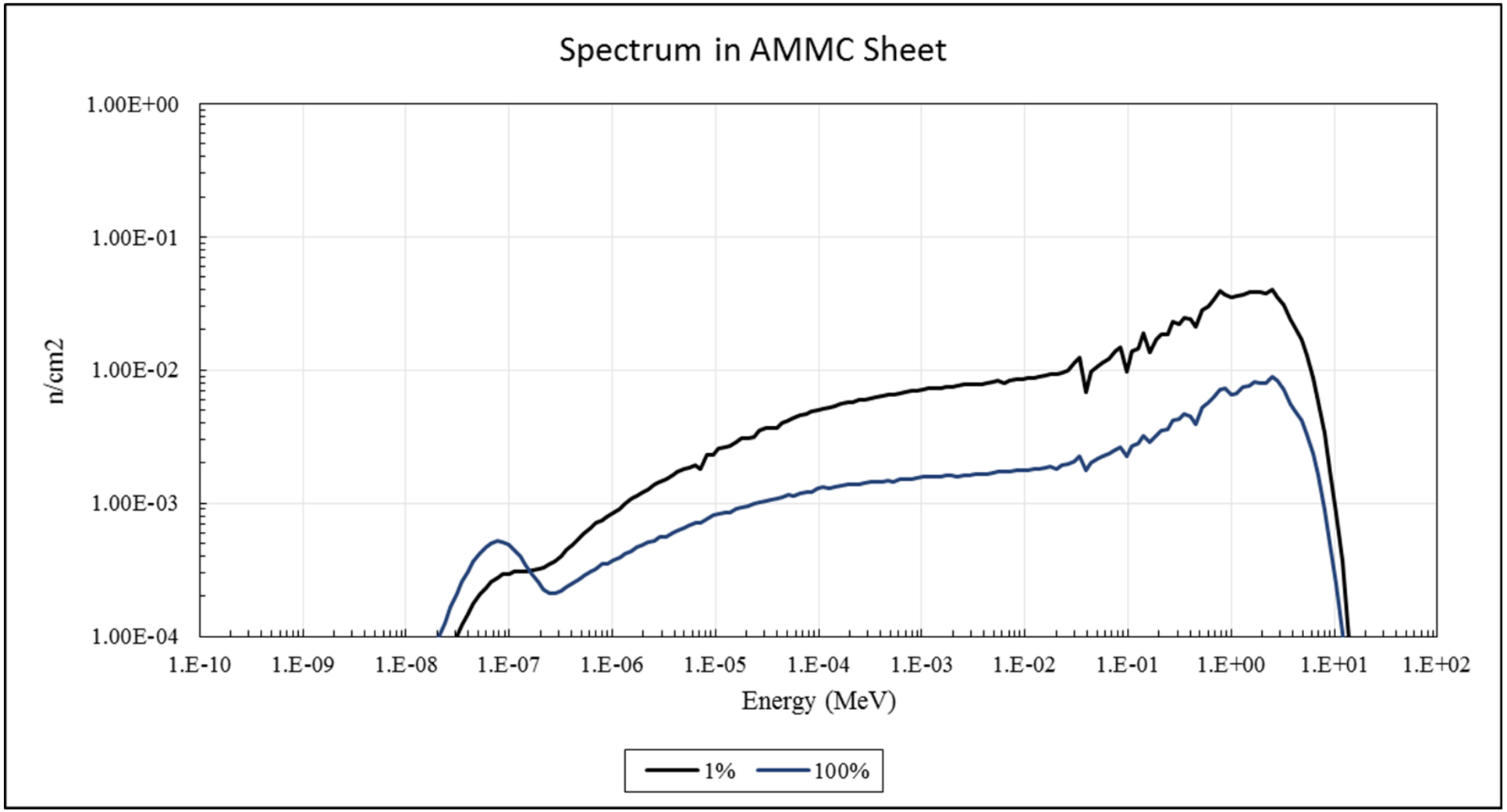
B-10 Absorption

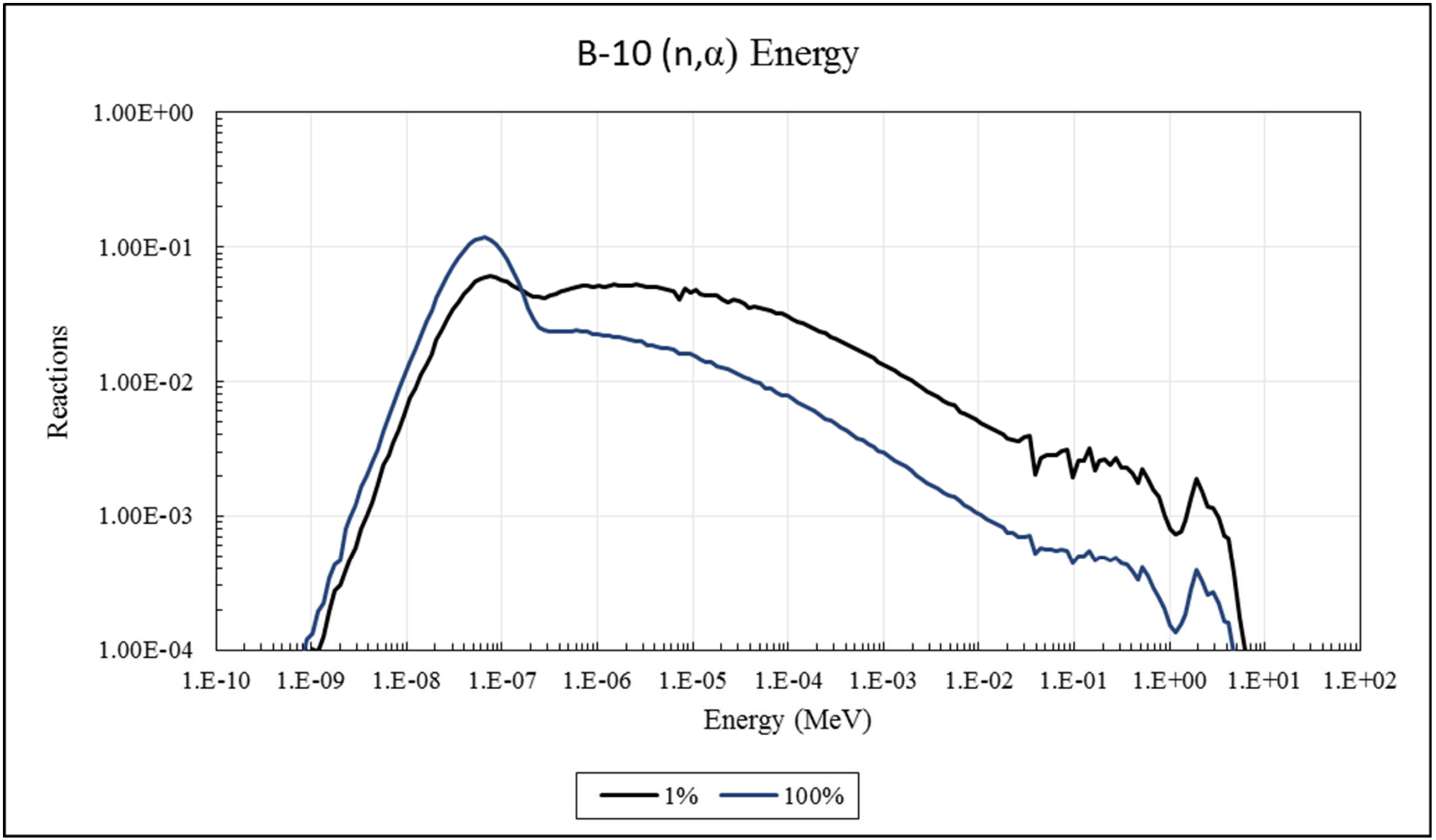
- Why is the B-10 absorption sensitive in the epithermal range and not thermal?

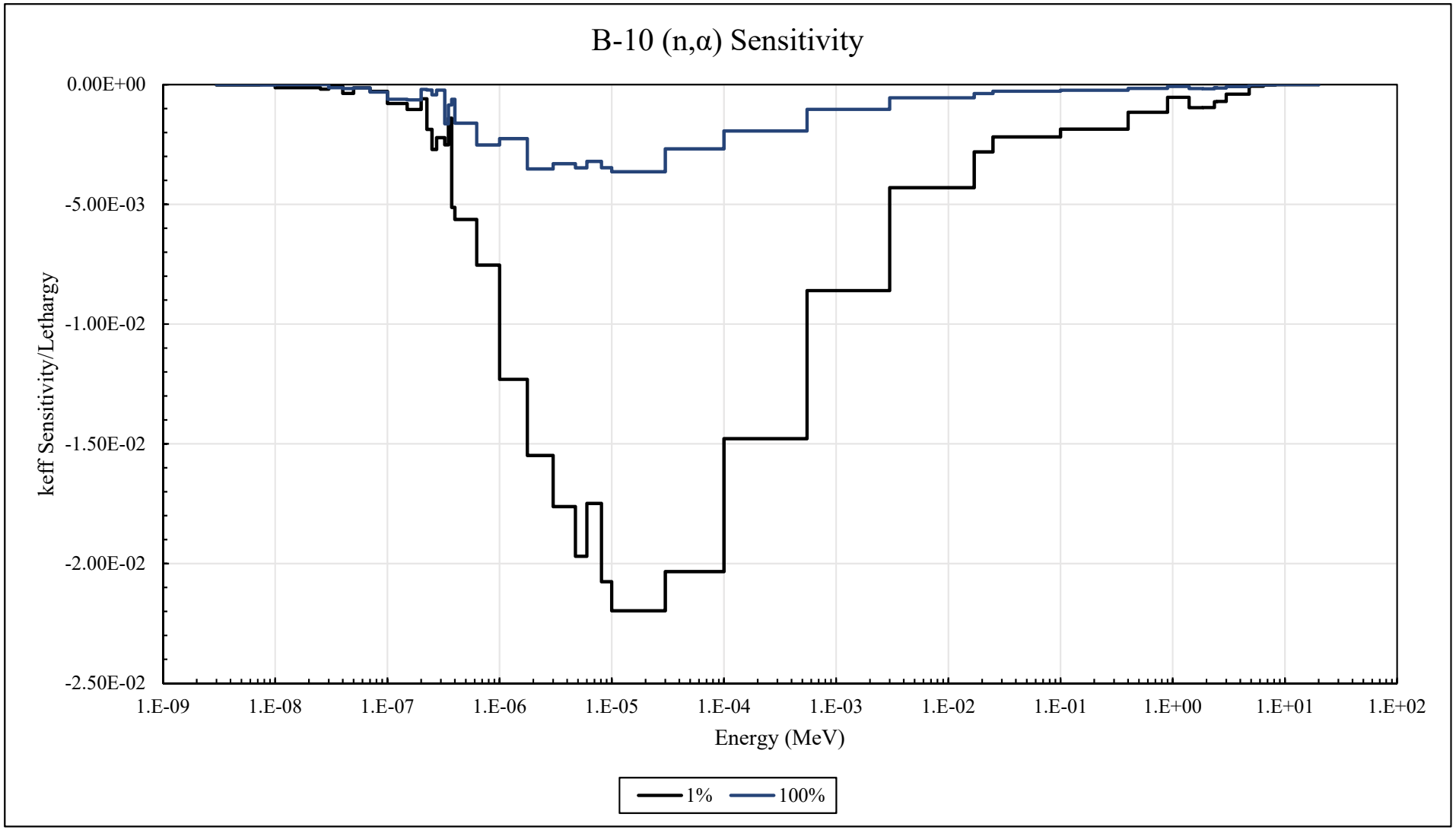
- Has B-10 absorption been validated?

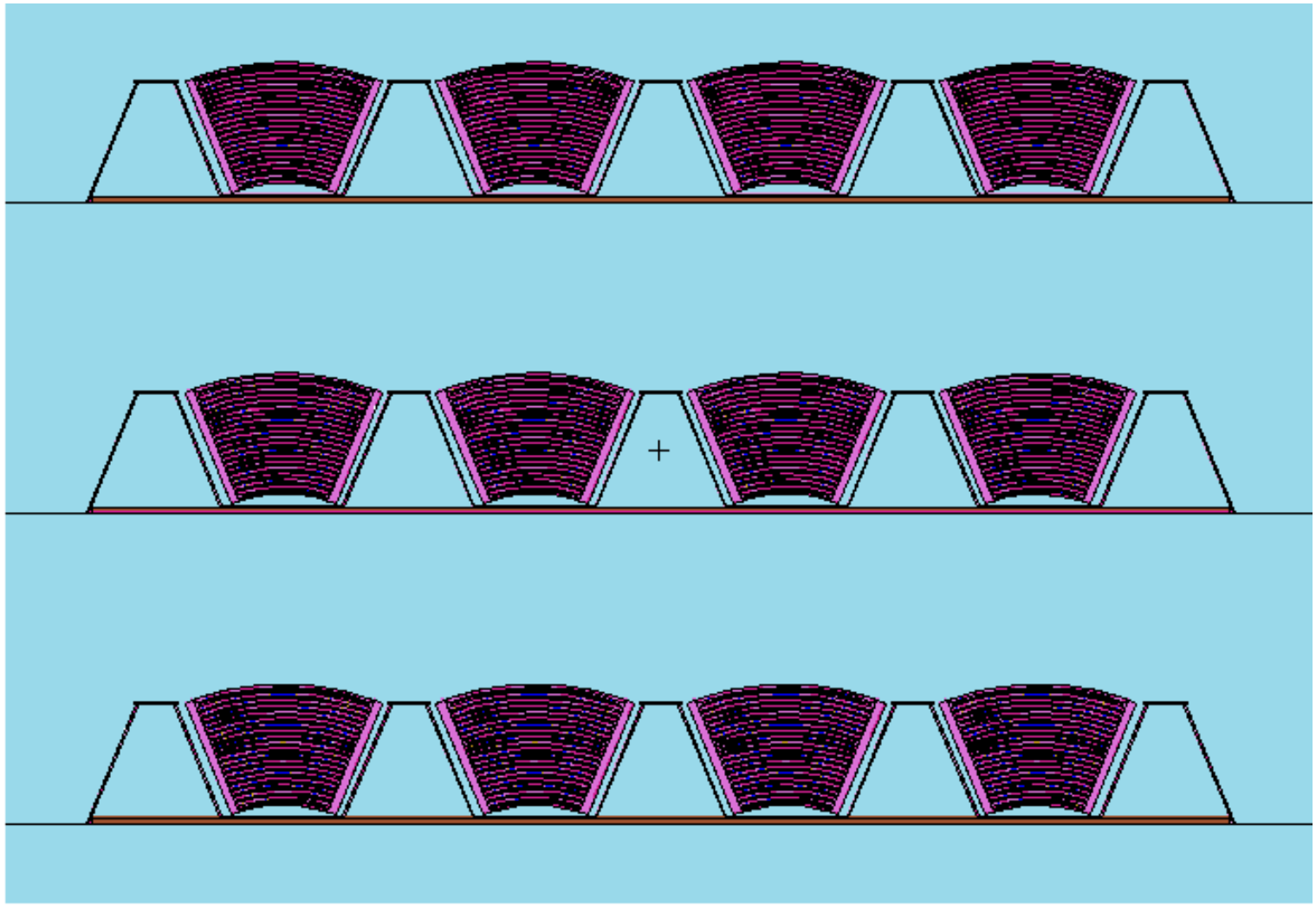





Spectrum in AMMC Sheet
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
n/cm2
1.E-10
1.E-09
1.E-08
1.E-07
1.E-06
1.E-05
1.E-04
1.E-03
1.E-02
1.E-01
1.E+00
1.E+01
1.E+02
Energy (MeV)
1%
100%


B-10 (n,α) Energy
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
Reactions
1.E-10
1.E-09
1.E-08
1.E-07
1.E-06
1.E-05
1.E-04
1.E-03
1.E-02
1.E-01
1.E+00
1.E+01
1.E+02
Energy (MeV)
1%
100%


B-10 (n,α) Sensitivity
0.00E+00
-5.00E-03
-1.00E-02
-1.50E-02
-2.00E-02
-2.50E-02
keff Sensitivity/Lethargy
1.E-09
1.E-08
1.E-07
1.E-06
1.E-05
1.E-04
1.E-03
1.E-02
1.E-01
1.E+00
1.E+01
1.E+02
Energy (MeV)
1%
100%

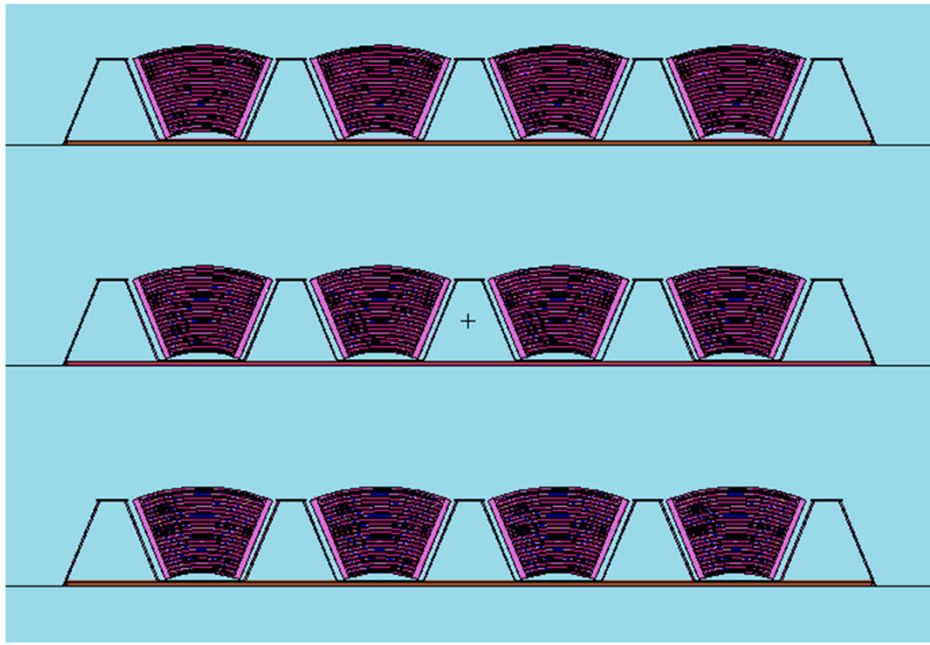


Sensitivity

- The sensitivity coefficient is defined as the ratio of relative change in k_{eff} to relative change in a system parameter:

$$S_{k,x} = \frac{dk/k}{dx/x} = \frac{x}{k}\frac{dk}{dx}$$

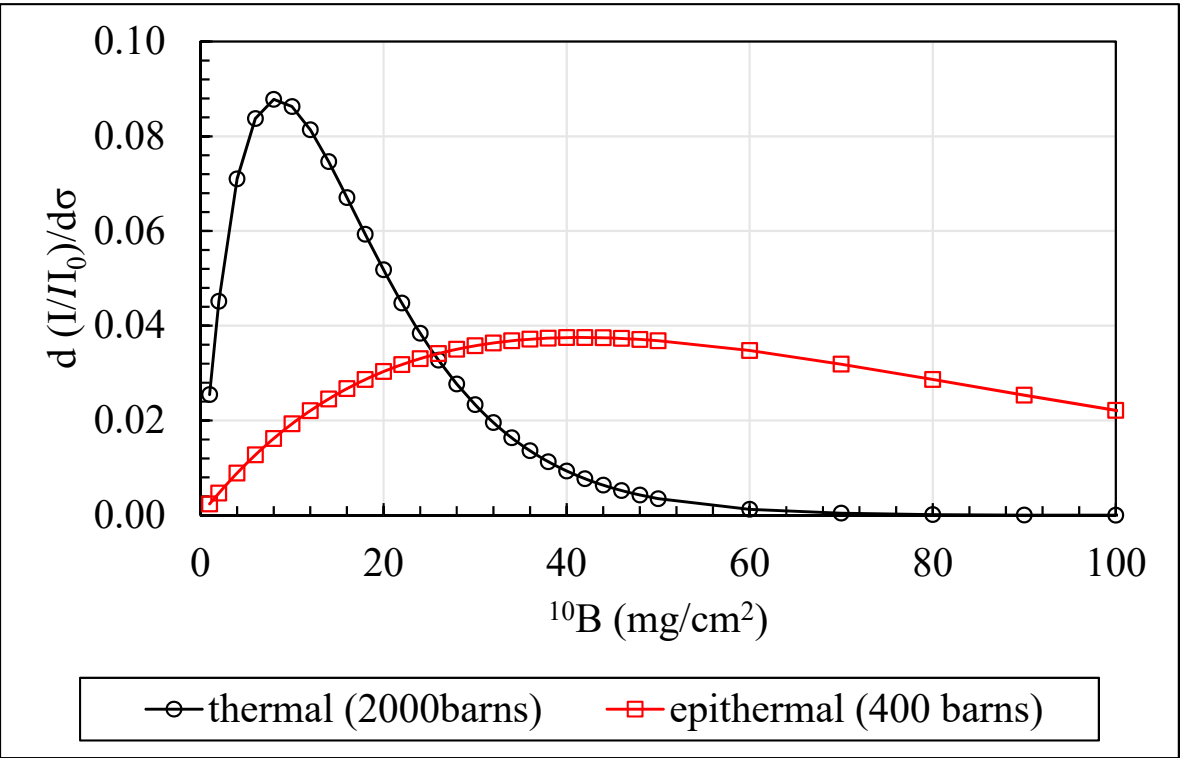
- The affect that boron has on k_{eff} is determined by the number of neutrons that pass through the AMMC sheet. More attenuation in the AMMC sheet results in a lower k_{eff}.
- FOR THIS PROBLEM, the k_{eff} sensitivity to B-10 is proportional to the attenuation in the AMMC sheet for a change in the B-10 cross section.

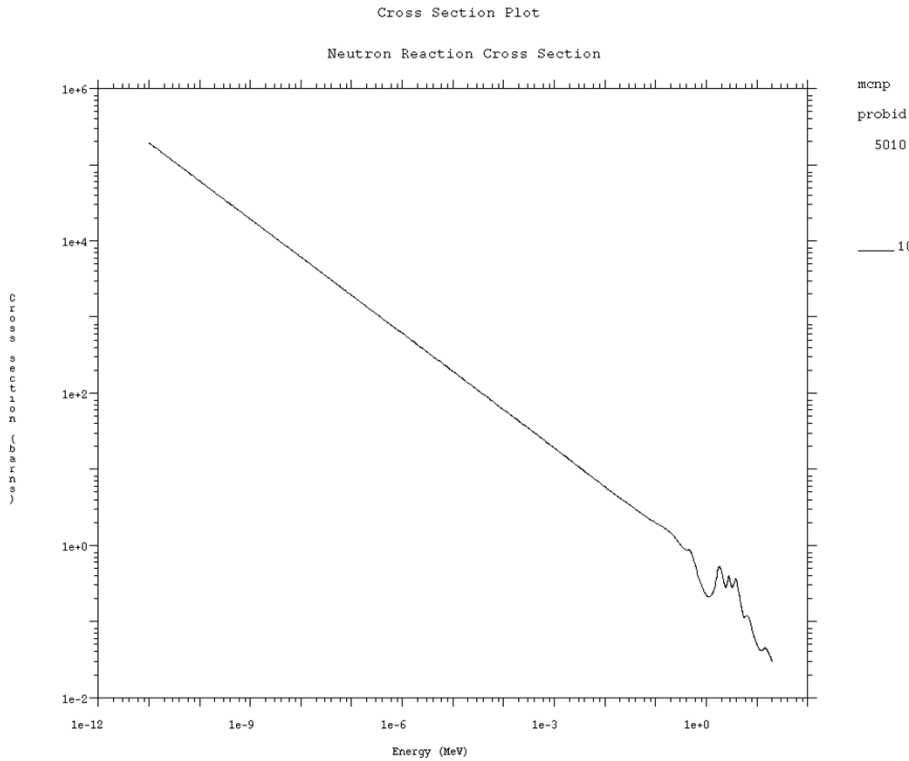


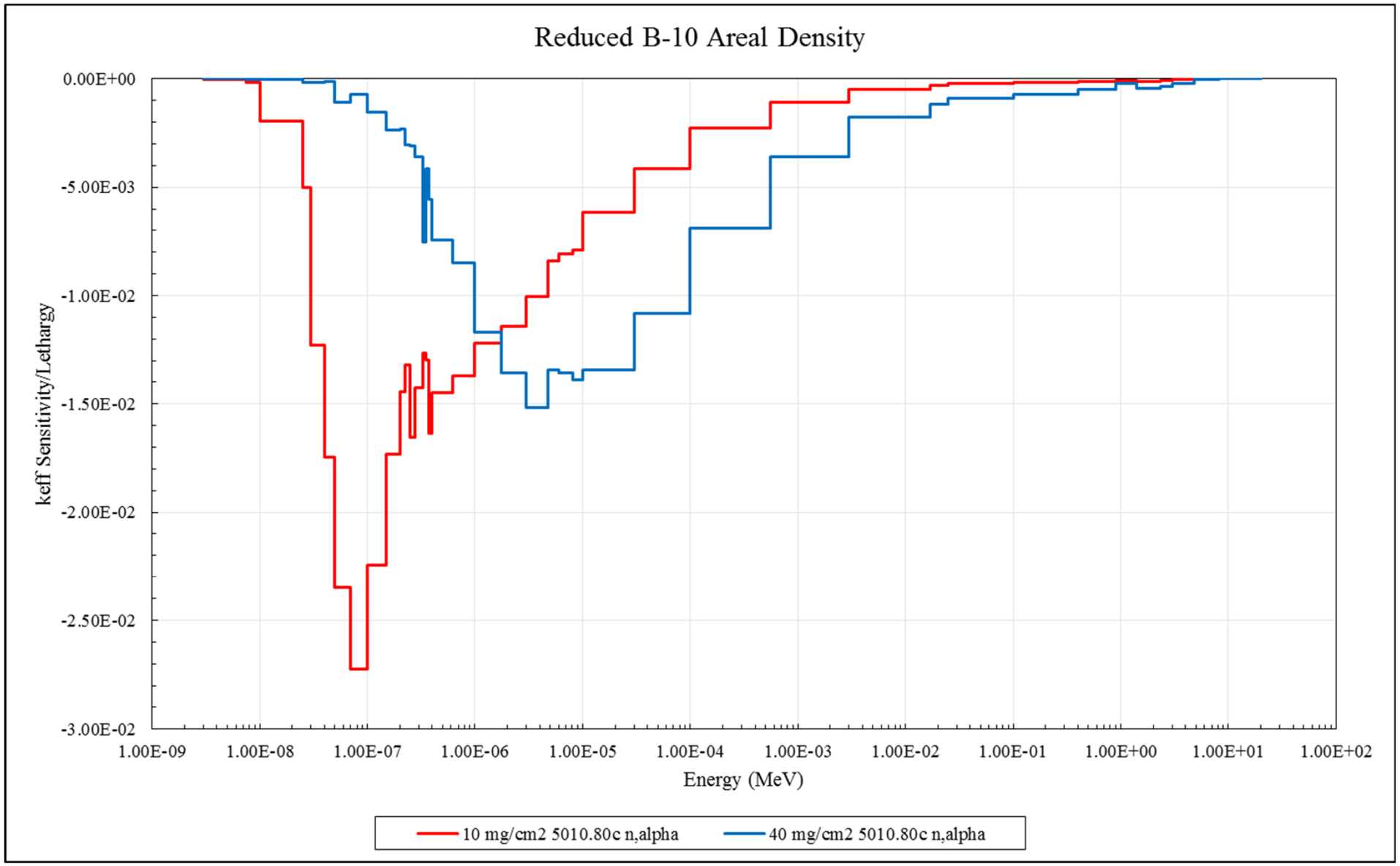
Sensitivity

$$\frac{I}{I_0} = e^{-\Sigma t} = e^{-N_a \sigma \rho_A / M}$$

$$\frac{\Delta k_{eff}}{\Delta \sigma} \propto \frac{d\, I/I_0}{d\, \sigma} = \frac{-N_a \rho_A}{M} e^{-N_a \sigma \rho_A / M}$$






Reduced B-10 Areal Density
0.00E+00
-5.00E-03
-1.00E-02
-1.50E-02
-2.00E-02
-2.50E-02
-3.00E-02
keff Sensitivity/Lethargy
1.00E-09
1.00E-08
1.00E-07
1.00E-06
1.00E-05
1.00E-04
1.00E-03
1.00E-02
1.00E-01
1.00E+00
1.00E+01
1.00E+02
Energy (MeV)
10 mg/cm2 5010.80c n,alpha
40 mg/cm2 5010.80c n,alpha

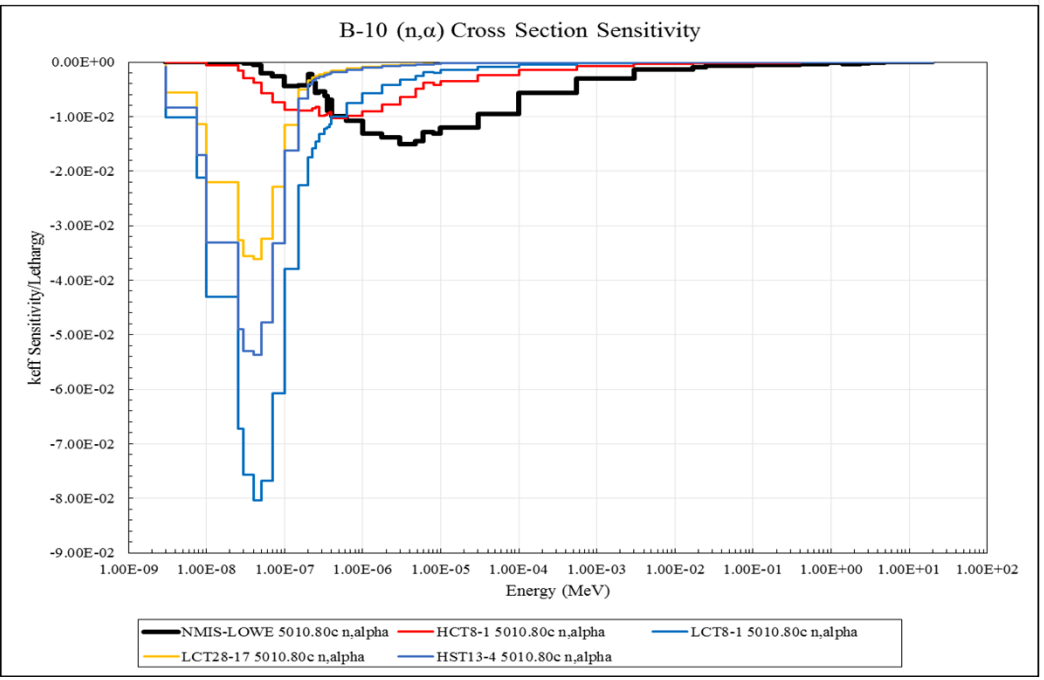
How to Validate B-10

- Is there a need to validate boron in the epithermal range?
- Whisper uses KSEN to get sensitivity coefficients for 12 reactions at 44 energies for every isotope in deck.
- What if Whisper only uses the B-10 sensitivities?

- *whisper_mcnp.pl –iso 5010.80c nmis_input*

Modified Whisper

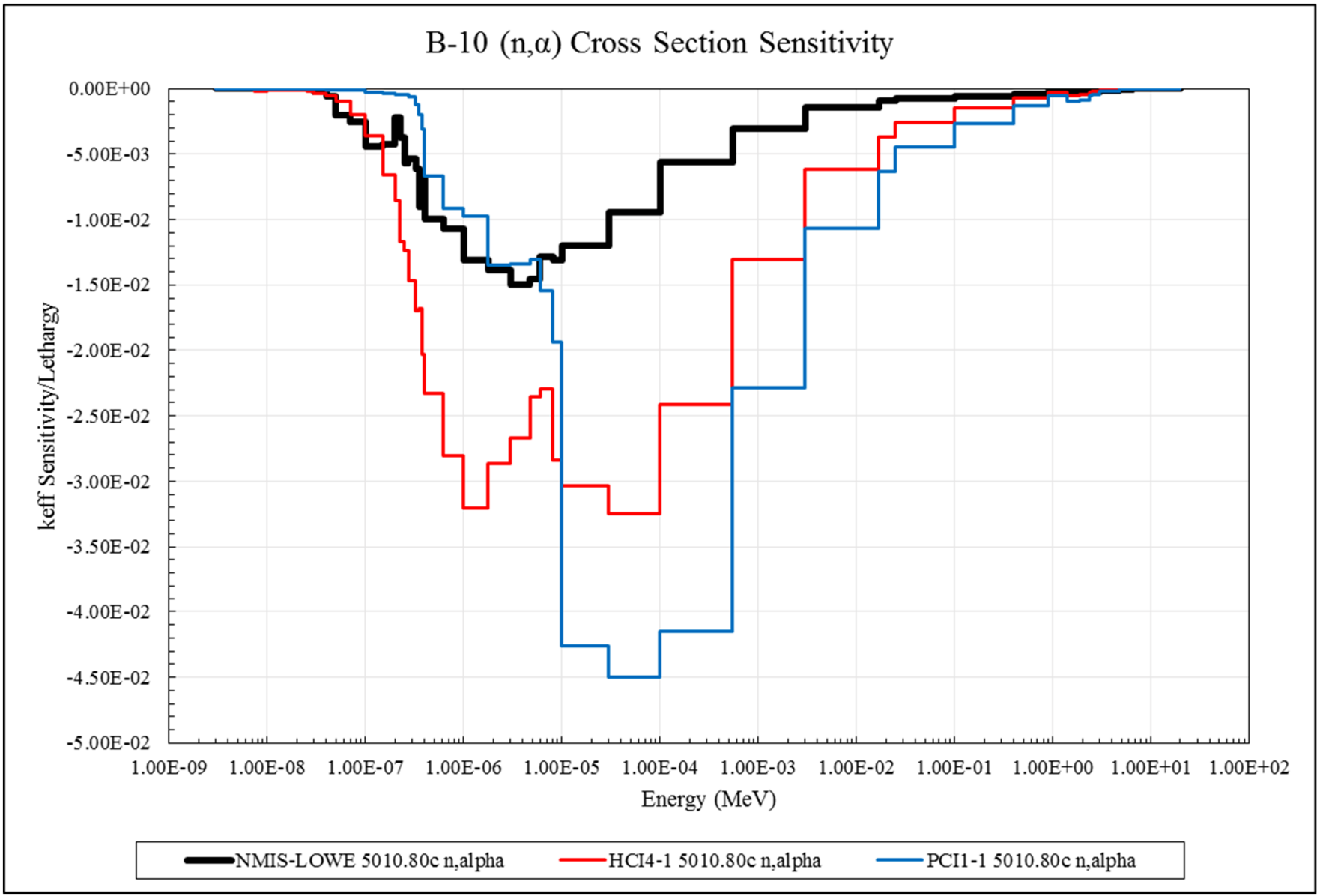
- HECTOR (Hot Enriched Carbon-moderated Thermal Oscillator Reactor) at Winfrith, UK
- Plutonium, boron, graphite



application	calc margin	data unc (1-sigma)	baseline USL
LOWE-115mil_AlB4C_Plate-onlyATR-001wdens	0.04563	0.00029	0.94862

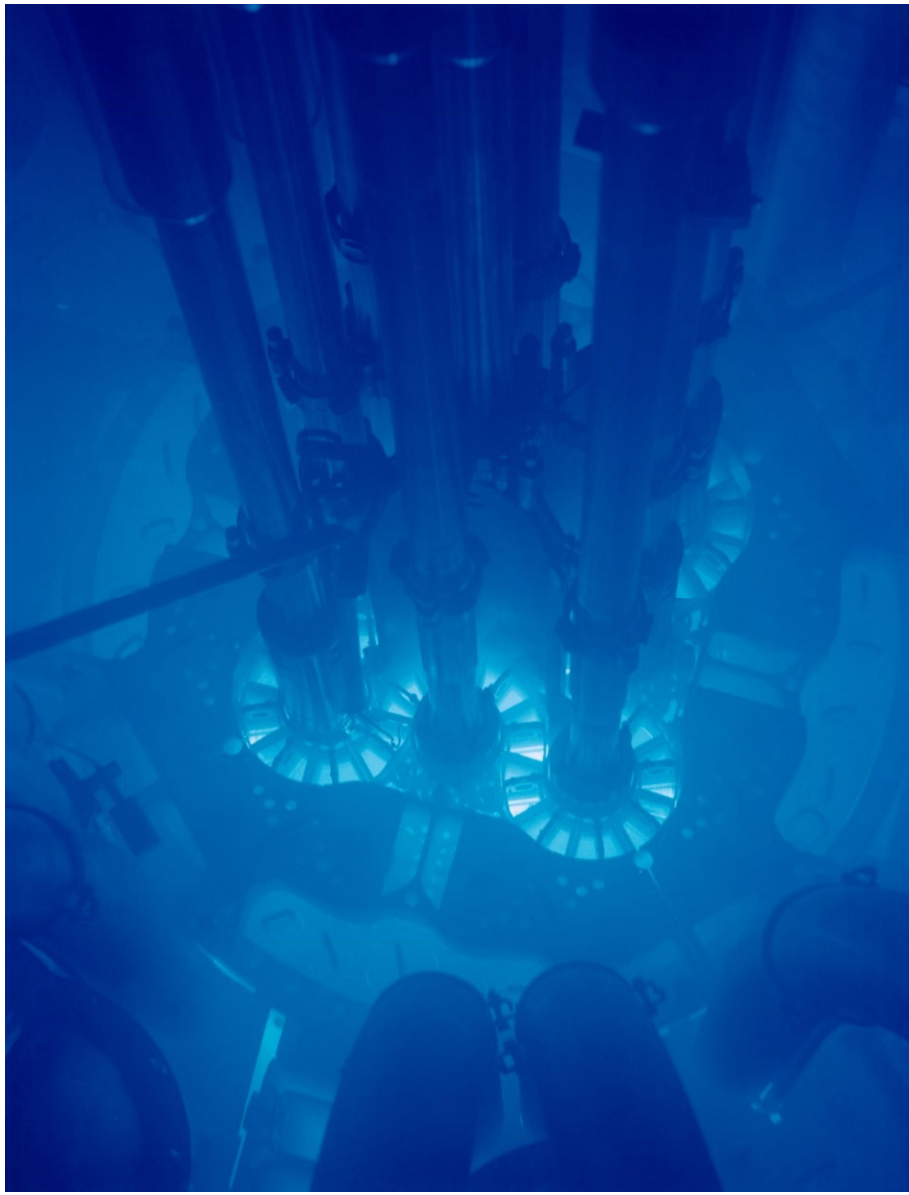
Benchmark population	=	111
Population weight	=	14.81842
Maximum similarity	=	0.09697
Bias	=	0.00821
Bias uncertainty	=	0.00782
Nuc Data uncert margin	=	0.00029
Software/method margin	=	0.00500
Non-coverage penalty	=	0.02960

benchmark	ck	weight
leu-comp-therm-008-001.i	0.0970	1.0000
leu-comp-therm-008-002.i	0.0968	0.9984
leu-comp-therm-008-011.i	0.0964	0.9944
leu-comp-therm-008-005.i	0.0885	0.9127
leu-comp-therm-008-007.i	0.0807	0.8321
leu-comp-therm-011-002.i	0.0705	0.7270
leu-comp-therm-011-003.i	0.0696	0.7181
leu-comp-therm-011-007.i	0.0673	0.6937
leu-comp-therm-008-008.i	0.0667	0.6883
leu-comp-therm-011-009.i	0.0635	0.6551
pu-comp-inter-001-001.i	0.0514	0.5304
heu-sol-therm-013-004.i	0.0473	0.4874
heu-sol-therm-013-003.i	0.0405	0.4176
leu-comp-therm-028-012.i	0.0380	0.3921
mix-comp-therm-002-004.i	0.0346	0.3570
leu-comp-therm-028-017.i	0.0339	0.3499
leu-comp-therm-028-004.i	0.0331	0.3412
u233-sol-therm-001-005.i	0.0285	0.2935
leu-comp-therm-028-003.i	0.0252	0.2600
leu-comp-therm-028-018.i	0.0239	0.2469
heu-sol-therm-013-002.i	0.0229	0.2363
u233-sol-therm-001-004.i	0.0220	0.2274
leu-comp-therm-028-011.i	0.0165	0.1696


B-10 (n,α) Cross Section Sensitivity
0.00E+00
-5.00E-03
-1.00E-02
-1.50E-02
-2.00E-02
-2.50E-02
-3.00E-02
-3.50E-02
-4.00E-02
-4.50E-02
-5.00E-02
keff Sensitivity/Lethargy
1.00E-09
1.00E-08
1.00E-07
1.00E-06
1.00E-05
1.00E-04
1.00E-03
1.00E-02
1.00E-01
1.00E+00
1.00E+01
1.00E+02
Energy (MeV)
NMIS-LOWE 5010.80c n,alpha
HCI4-1 5010.80c n,alpha
PCI1-1 5010.80c n,alpha

Conclusion

- Whisper is a great tool and was valuable in finding applicable benchmarks.
- The sensitivity study helped me understand the problem much better.
- Whisper was used to find benchmarks to validate specific isotopes.



- Sensitivity and uncertainty analysis tools may be used to strengthen and improve a validation analysis by aiding in the selection of applicable critical experiments, to improve the understanding of fissionable systems, and to assist in assessing the adequacy of an existing validation. DOE-STD-3007-2017