Testing ENDF/B-VIII.0β Data Files with ICSBEP Benchmarks

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Abstract

We review and compare criticality data testing results performed at Los Alamos with ENDF/B-VII.1 and ENDF/B-VIII.0β nuclear data evaluations.

Outline

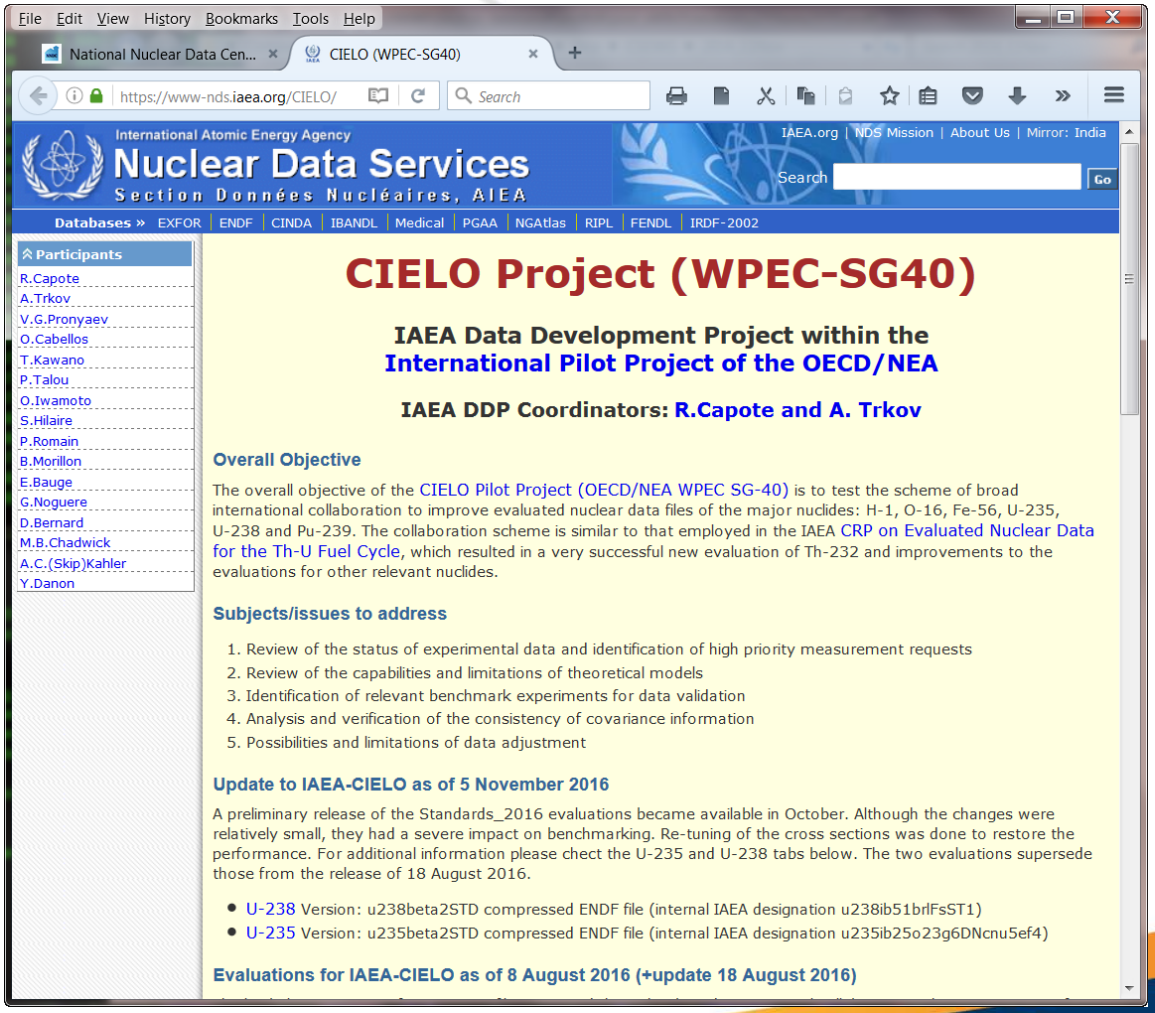
- ENDF/B-VIII.0β3 Overview
  - A caution about NJOY Processing and Doppler broadening!
- Data Testing
  - Criticality calculations with ICSBEP HMF, HMI, HST, IMF, LCT, PMF, PMI and PST benchmarks.
- Summary

ENDF/B-VIII.0β3

- ENDF/B-VIII.0β3 files are available from the BNL NNDC: (https://ndclx4.bnl.gov/gf/project/endf/).

CIELO

- The IAEA Nuclear Data Section has created a CIELO web page … https://www-nds.iaea.org/CIELO/ … with links to candidate evaluated data files.



An NJOY Processing Caution …

- A note of caution when Doppler broadening evaluated data files …
  - NJOY's default upper energy limit for Doppler broadening is the lowest energy among …
    - The top of the resolved resonance range;
    - The lowest reaction threshold;
    - A user input value (`thnmax`);
    - 1.0 MeV.
  - If the user input, `thnmax`, is negative then Doppler broadening will occur up to |`thnmax`|, regardless of the other criteria.
  - For many years the "top of the resolved resonance range" was the de facto upper limit.
    - It has become increasingly common in modern evaluated data files for lowest reaction threshold to establish the Doppler broadening upper limit.

An NJOY Processing Caution …

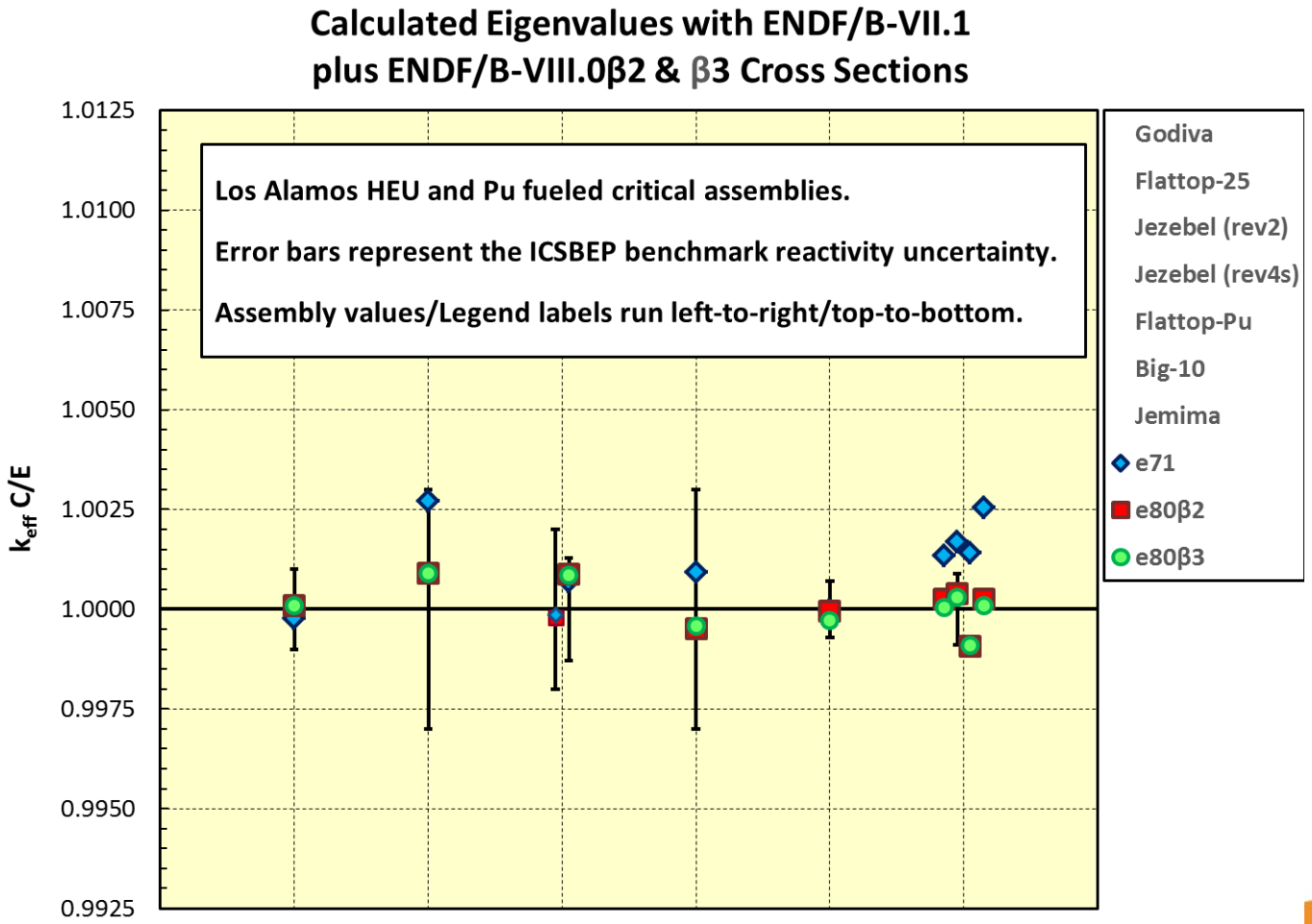
- The following ENDF/B-VII.0β nuclides may require definition of |`thnmax`| in the User's input deck to assure Doppler broadening occurs through the top of the resolved resonance range …
  - ^{23}Na, ^{32}S, ^{35}Cl, ^{38}Ar, ^{41}K, ^{45}Sc, ^{50}V, ^{52}Cr, $^{54,\mathbf{56},57}$**Fe**, ^{58}Co, ^{65}Cu, ^{64,66,68,70}Zn, ^{70,72,73}Ge, $^{\mathbf{235,238}}$**U**.
    - **CIELO nuclides are highlighted in red.**
- NJOY/BROADR's standard output contains the statement … "`max energy for broadening and thinning = x.xxxxE+xx`" … so that User's know the maximum Doppler broadening energy for any particular NJOY job.

ICSBEP Benchmark Data Testing

- ICSBEP Nomenclature …
  - XXX-YYY-ZZZ-###, where XXX=fuel material; YYY=fuel form; ZZZ=spectrum; ###=sequence number.
- Data testing categories discussed herein …
  - FAST Los Alamos systems: HMF1 (Godiva), HMF28 (Flattop-25), IMF1 (Jemima), IMF7 (Big-10), PMF1 (Jezebel), PMF6 (Flattop-Pu).
  - HMF7: A suite of ORNL assemblies with HEU plates and polyethylene.
  - HST: HEU solution systems with varying leakage.
  - PST: Pu solution systems with varying leakage.
  - LCT: UO_2 lattice configurations.
  - HMF, HMI, PMF, PMI & LCT systems with iron/steel.
  - PMF systems with various reflectors.

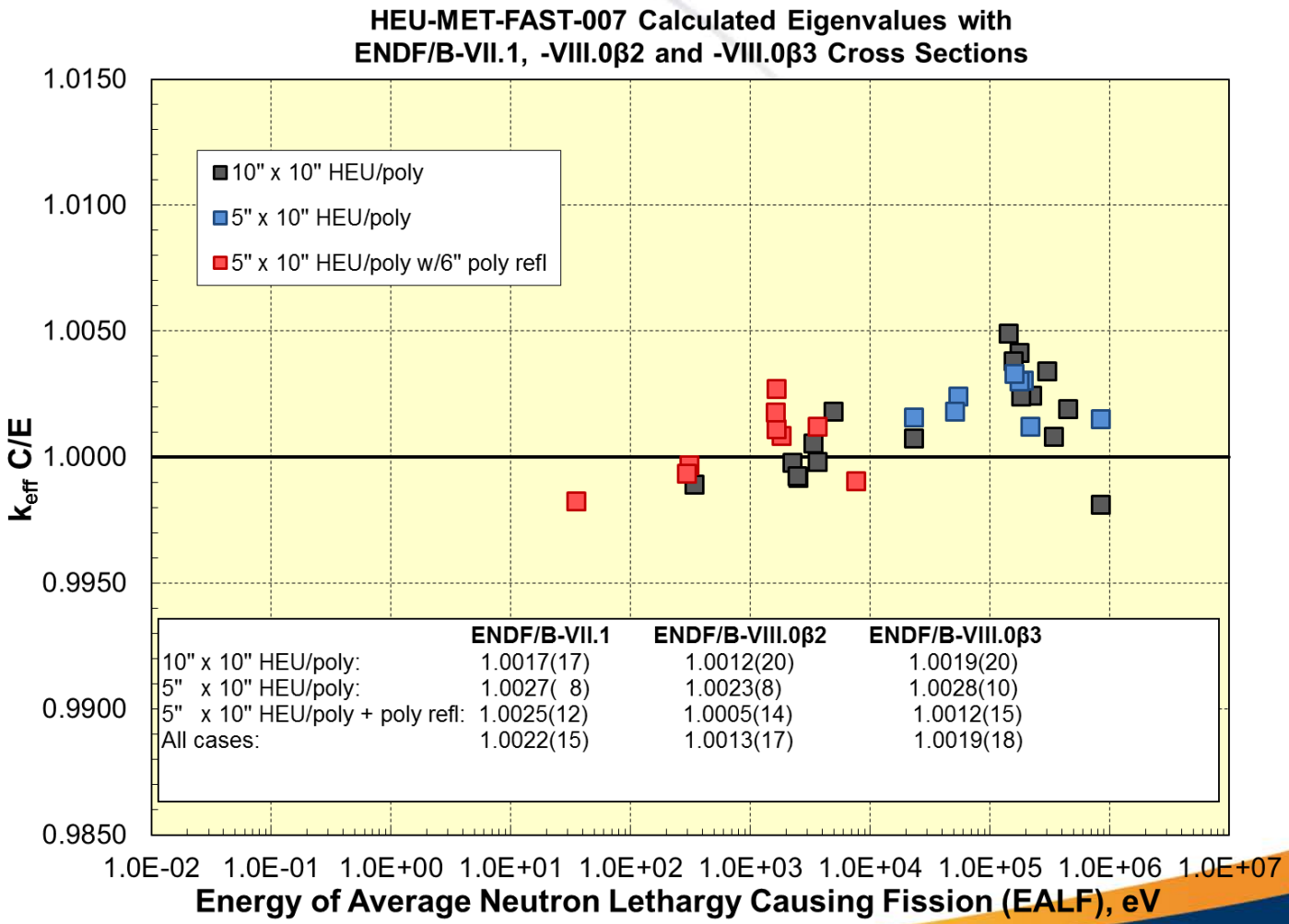
"FAST" Los Alamos Assemblies

- HMF1 (Godiva)
- HMF28 (Flattop-25)
- PMF1 (Jezebel)
- PMF6 (Flattop-Pu)
- IMF7 (Big-10)
- IMF1 (Jemima)



HMF7

- A suite of HEU metal plates and polyethylene assemblies
  - Varying degrees of moderation test our nuclear data over an energy range from tens of eV to an MeV.



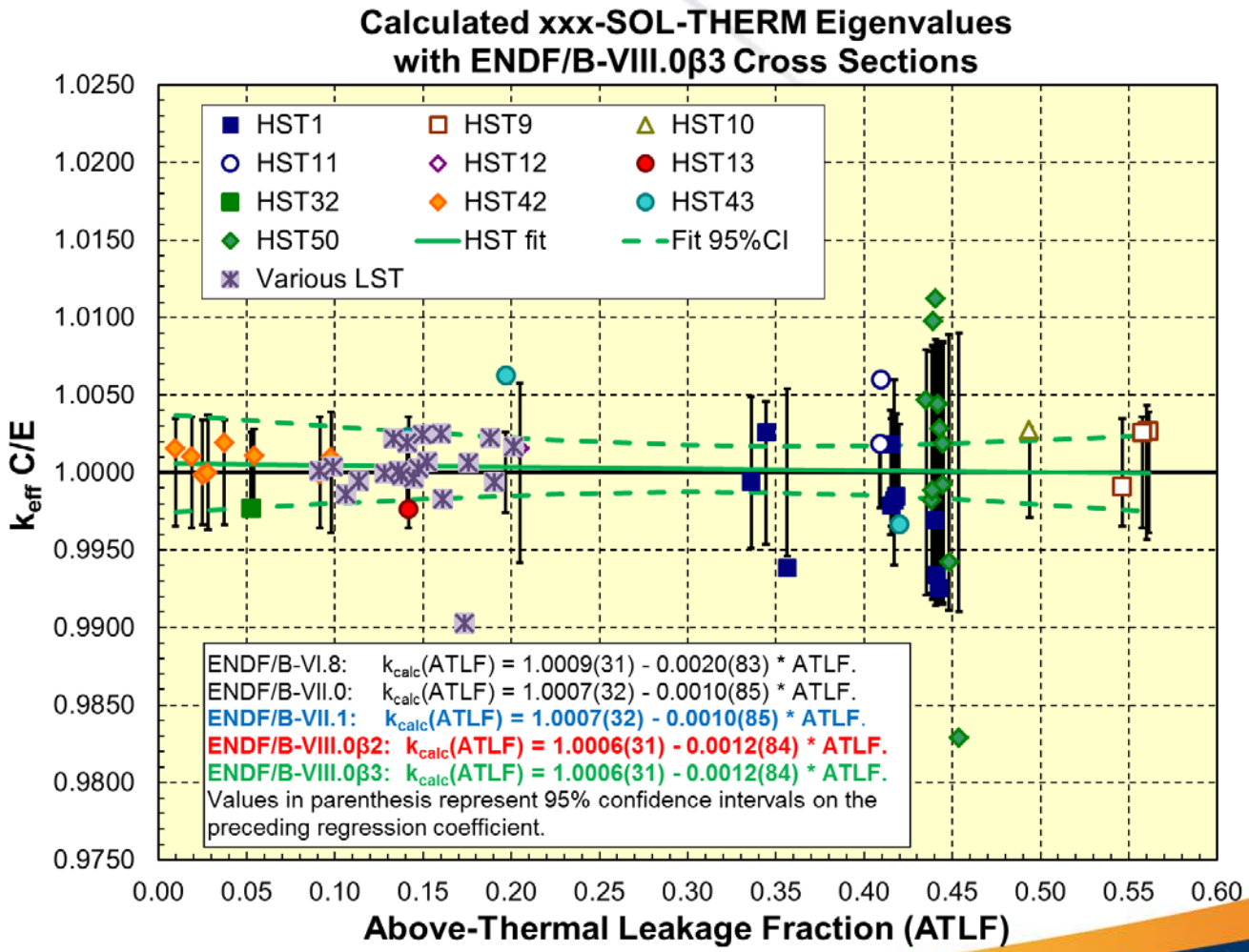
	ENDF/B-VII.1	ENDF/B-VIII.0β2	ENDF/B-VIII.0β3
10" x 10" HEU/poly:	1.0017(17)	1.0012(20)	1.0019(20)
5" x 10" HEU/poly:	1.0027(8)	1.0023(8)	1.0028(10)
5" x 10" HEU/poly + poly refl:	1.0025(12)	1.0005(14)	1.0012(15)
All cases:	1.0022(15)	1.0013(17)	1.0019(18)

HST Benchmarks - ^{235}U (& ^{1}H, ^{16}O)

- A suite of 42 HEU-SOL-THERM benchmark critical configurations has been used for many years.
  - Accurate calculated eigenvalues, correlated against Above-Thermal Leakage Fraction (ATLF), have been obtained since ENDF/B-VI.3 in the early 1990s.
    - No trends observed for other regression analyses such as k_{calc} versus Above-Thermal Fission Fraction (ATFF); versus Average Energy of a Neutron causing Fission (EAF); versus Energy of Average Lethargy of a Neutron causing Fission (EALF) or versus solution H/U ratio.
  - Tests of revised data sets must answer the question … “are we still ok or did we break something?”.

HST Benchmarks - ^{235}U (& ^{1}H, ^{16}O)

- … and the answer is "we are still ok".
- For e80β3 + IAEA "STD" $^{235,238}U$ files the intercept and slope are:
  - 1.0006(31)
  - -0.0009(84).

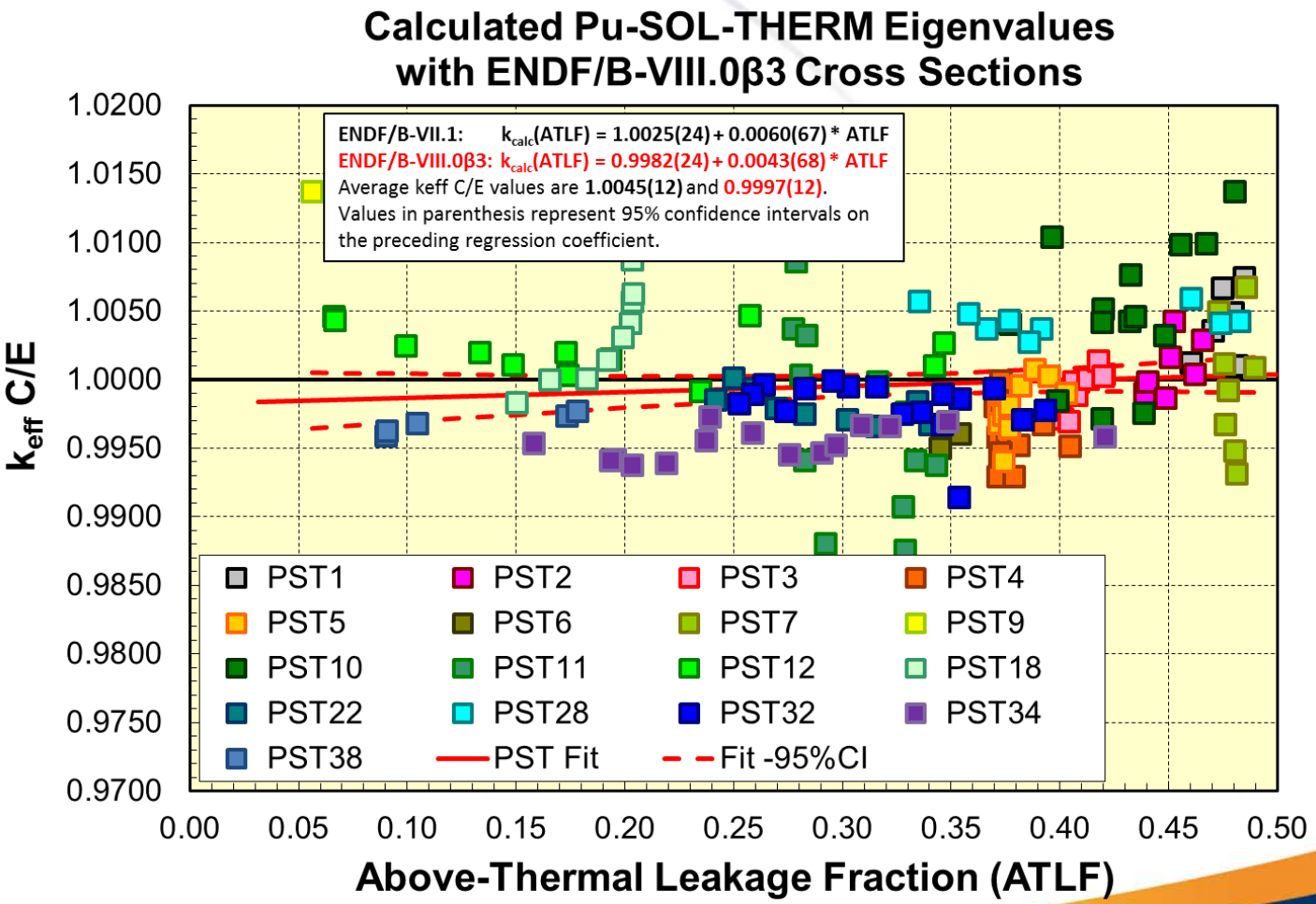


PST Benchmarks - ^{239}Pu (& ^{1}H, ^{16}O)

- A suite of 158 Pu-SOL-THERM benchmark critical configurations have exhibited a long standing k_{calc} bias for many years and for many generations of evaluated data sets.
  - The average k_{eff} C/E bias is about 450 pcm with ENDF/B-VII.1.
    - Work by WPEC Sub-Group 34 lead to revisions to the ^{239}Pu evaluated data file (primarily RR parameters and nu(e)) which eliminated about 75% of this bias.
  - Tests of revised data sets must answer the question … “have we made further improvements in PST benchmark performance, have we taken a step backward, or is there more work to do?”.

PST Benchmarks - ^{239}Pu (& ^{1}H, ^{16}O)

- … and the answer is "there has been significant further improvement in benchmark performance"



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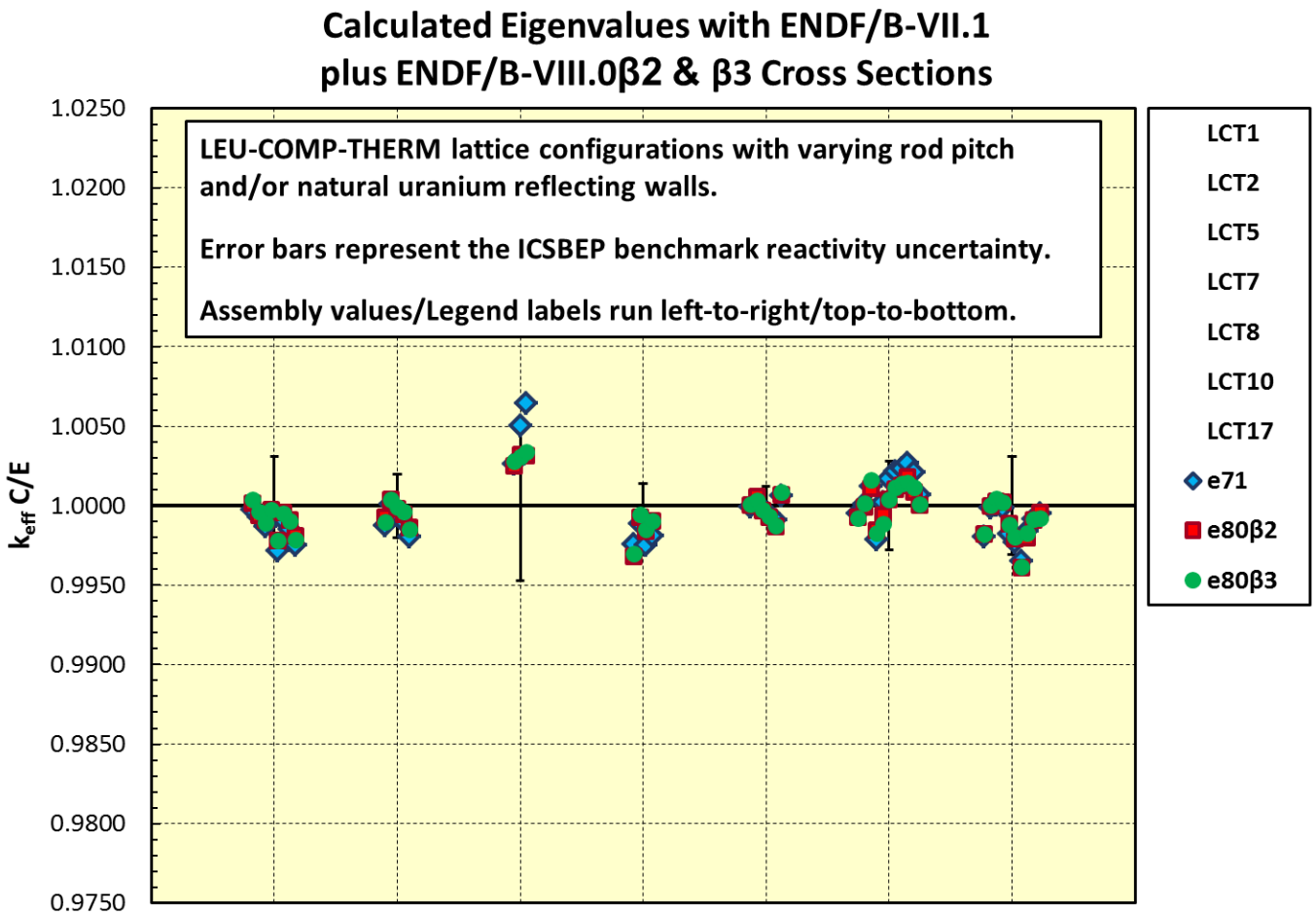
LCT Benchmarks – ^{235}U (& ^{1}H, ^{16}O, ^{238}U)

- Good e71 results for this benchmark category remain good with e80β2 and e80β3.

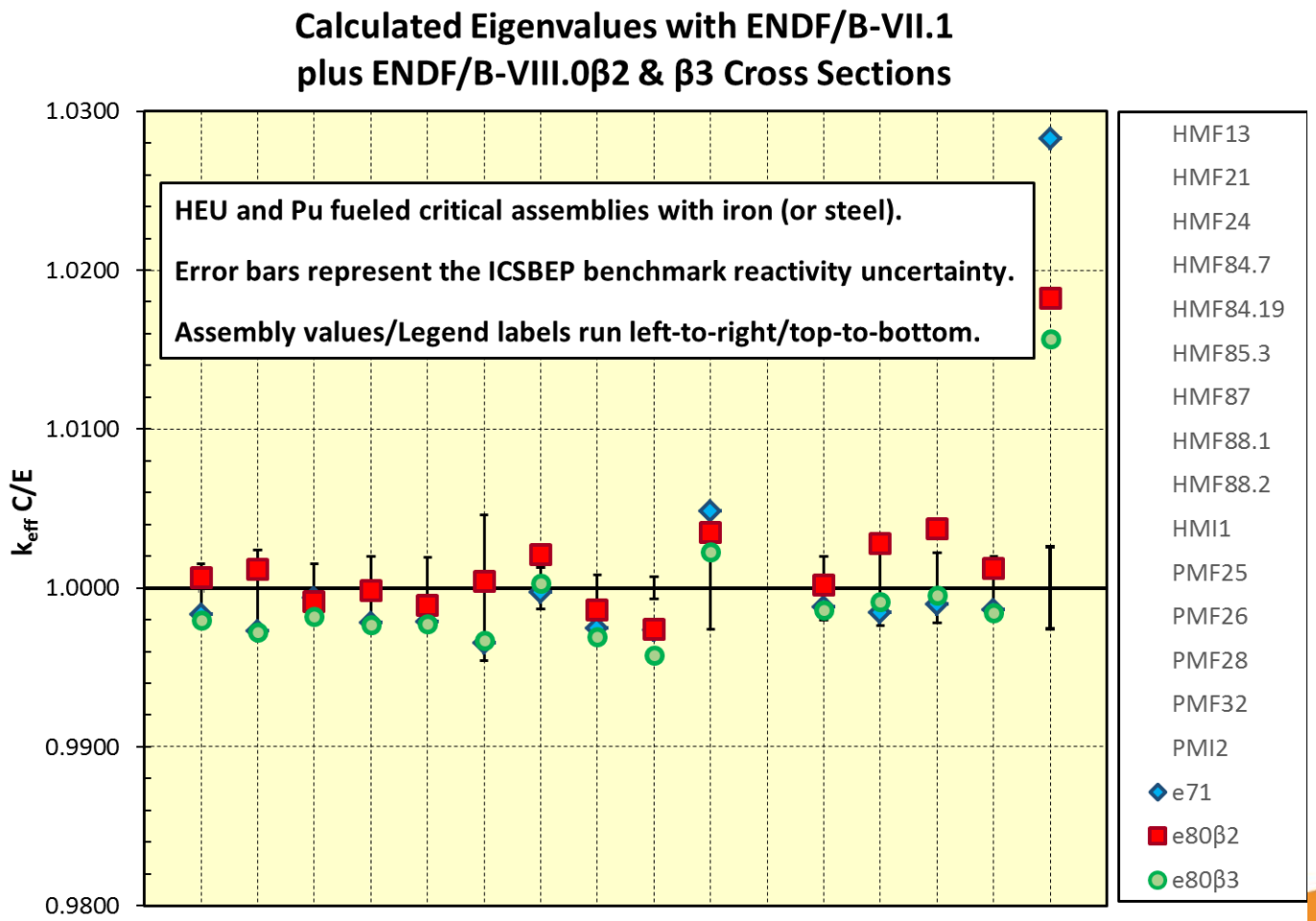


Assemblies with Iron (Steel)

- HMF13 – Spherical HEU assembly with 3.65 cm thick steel.
- HMF21 – Spherical HEU assembly with 9.7 cm thick steel.
- HMF24 – Spherical HEU assembly with 0.8 cm thick steel & 9.65 cm thick polyethylene.
- HMF84.7, 84.19 & 85.3 – Cylindrical HEU with Fe reflectors.
- HMF87 – HEU cylindrical assembly with interstitial steel.
- HMF88 – HEU cylindrical assembly with interstitial steel or steel & polyethylene plus a polyethylene radial/axial reflector.
- HMI1 – Argonne ZPR-9/34.
- LCT10, 17 & 42 – multiple UO_2 rod clusters with steel reflecting walls
- PMF25 – Spherical ^{239}Pu assembly with 1.55 cm thick steel.
- PMF26 – Spherical ^{239}Pu assembly with 11.9 cm thick steel.
- PMF28 – Spherical ^{239}Pu assembly with 19.65 cm thick steel.
- PMF32 – Spherical ^{239}Pu assembly with 4.49 cm thick steel.
- PMI2 – Argonne ZPR-6/10.

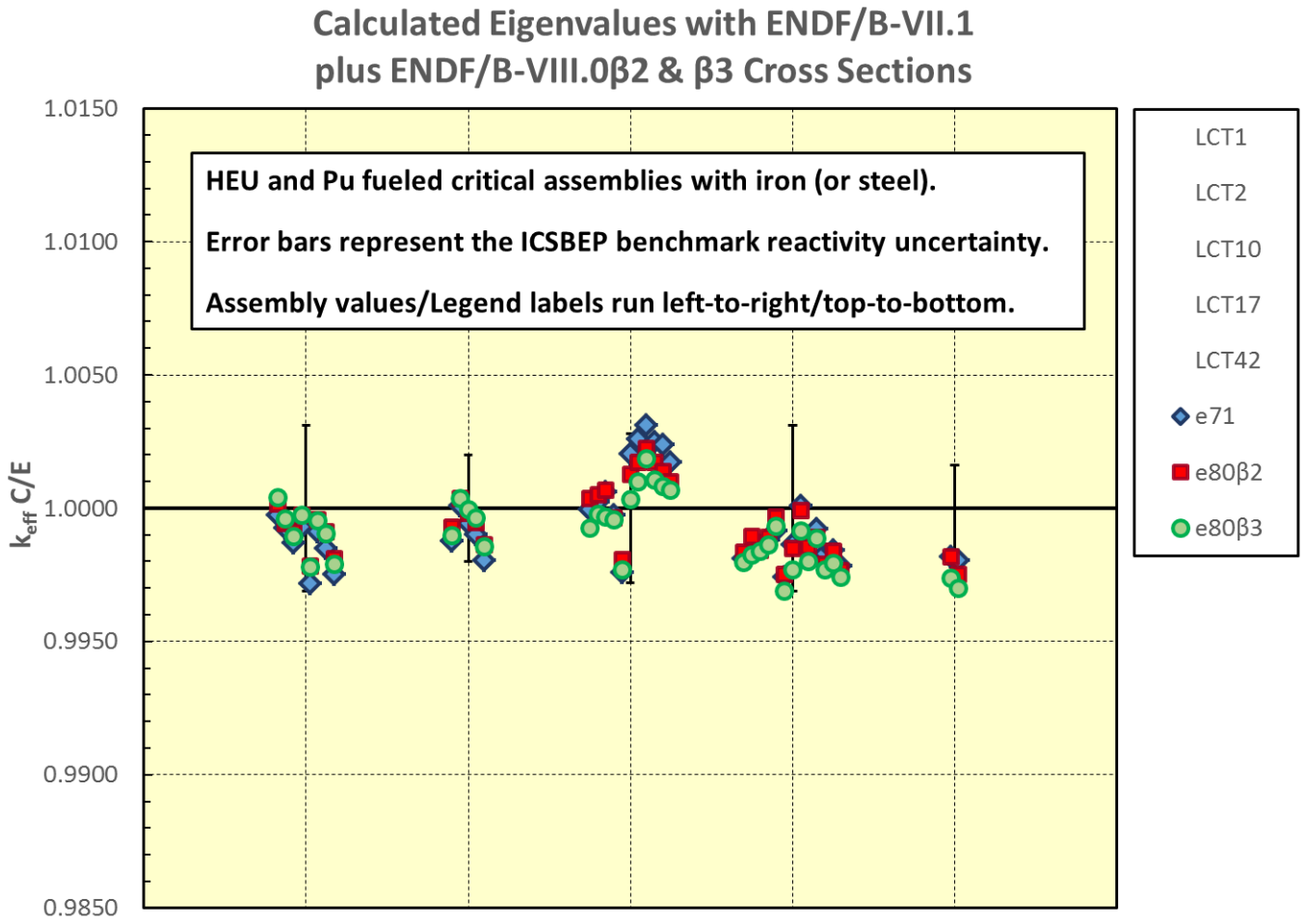
FAST Assemblies with Iron (Steel)

- Calculated eigenvalue changes with β2 or β3 cross sections are generally within the experimental uncertainty.



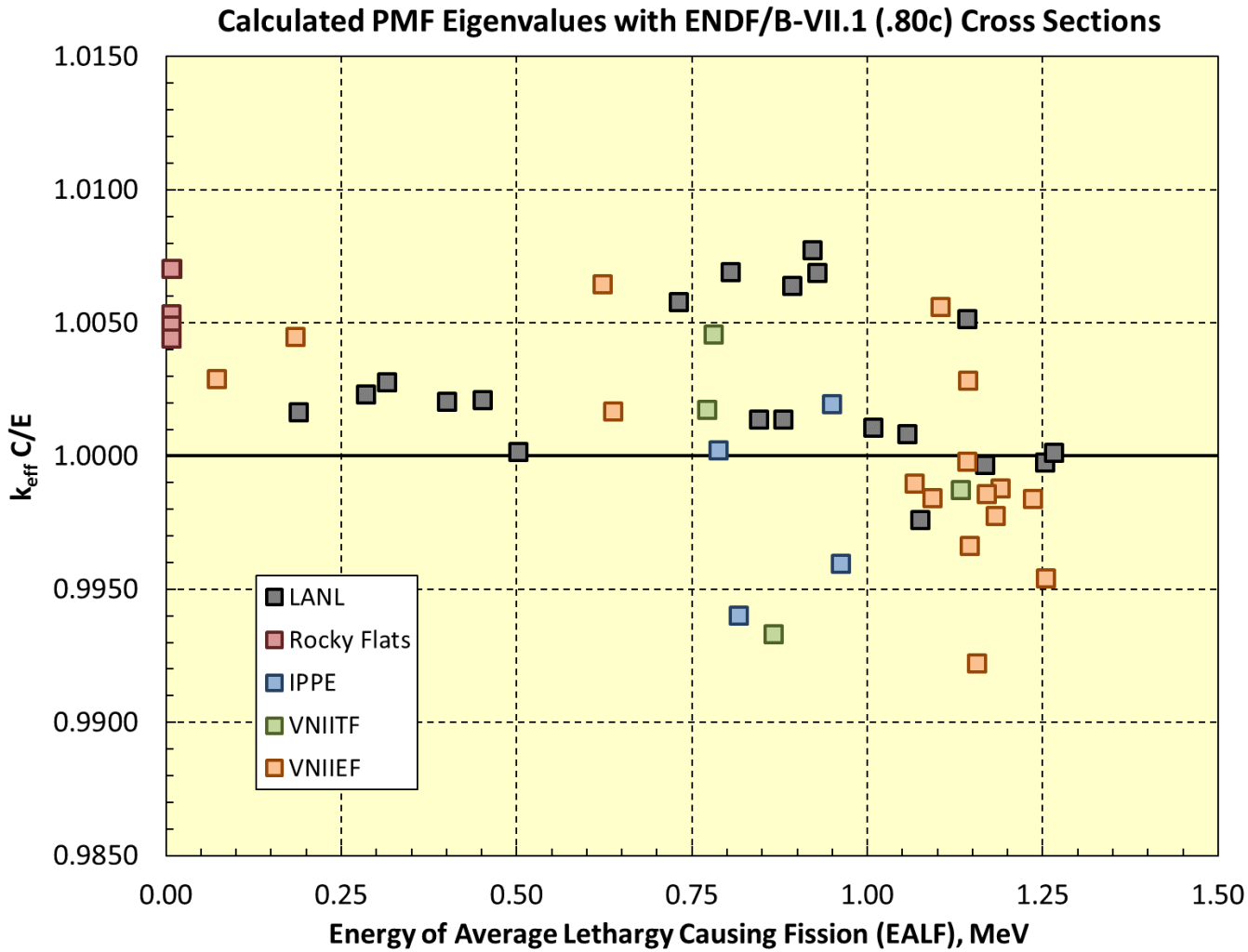
THERMAL Assemblies with Iron (Steel)

- Thermal assembly calculated eigenvalues remain accurate.



PMF Assemblies – ENDF/B-VII.1

- k_{eff} C/E exhibits a clear trend with ENDF/B-VII.1 cross sections



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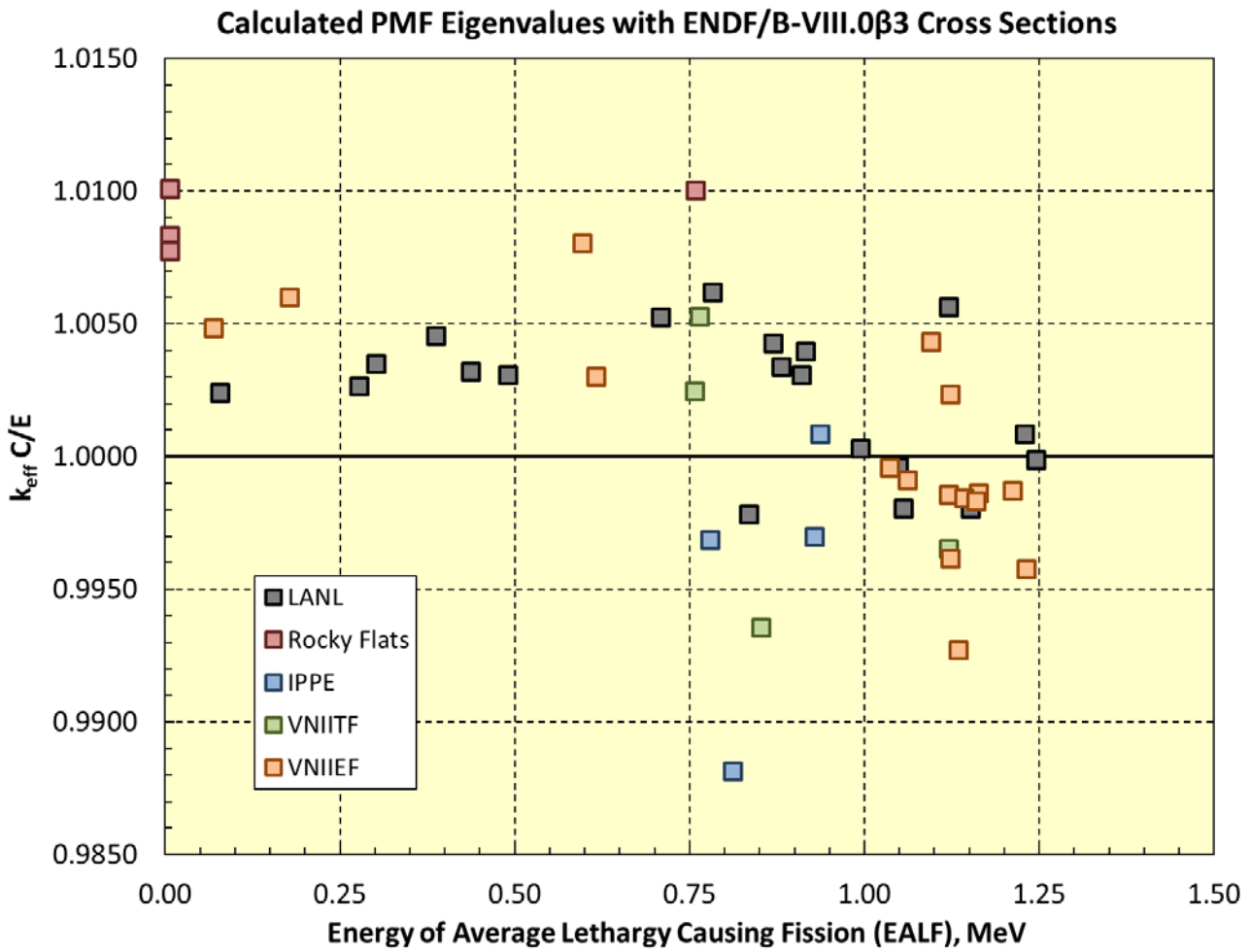
PMF Assemblies – ENDF/B-VIII.0β3

- Lots of changes when switch to ENDF/B-VIII.0β3, but there's more work to do here.



Summary

- LANL testing to date has concentrated on ICSBEP benchmark eigenvalues. Reaction rate (spectral indices) data, pulsed sphere spectra, shielding (SINBAD) and reactor physics (IRPhEP) benchmarks are also important resources to be utilized in a comprehensive data testing regimen (and are being utilized by our international colleagues).

- New tools are becoming available to assist data testing.
  - DICE = Database for ICSBEP
  - NDaST = Nuclear Data Sensitivity Tool (OECD/NEA).

Average Calculated Eigenvalues

- A high level summary of calculated eigenvalues, by ICSBEP category …

e71_80c					e80β2		
Category	#	Average kcalc C/E	kcalc C/E population stdev		#	Average kcalc C/E	kcalc C/E population stdev
HMF	262	1.00076	0.00352		254	1.00011	0.00364
HMI	5	1.00033	0.00464		5	1.00056	0.00280
HCI	12	1.01132	0.03884		12	1.01402	0.03336
HMM	11	1.00201	0.00404		11	0.99959	0.00358
HMT	4	1.00845	0.00556		4	1.00724	0.00490
HST	178	0.99858	0.00581		178	0.99853	0.00637
IMF	19	1.00208	0.00314		19	1.00064	0.00284
ICF	2	1.00059	0.00236		2	0.99894	0.00183
LST	20	0.99967	0.00265		20	1.00000	0.00263
LMT	6	0.99846	0.00286		6	0.99847	0.00210
LCT	247	0.99951	0.00259		247	0.99941	0.00252
PMF	53	1.00180	0.00454		53	1.00198	0.00556
PMI	3	1.01155	0.01451		3	1.00619	0.01042
PST	158	1.00451	0.00455		158	0.99974	0.00461
MMF	37	1.00370	0.00279		37	1.00346	0.00263
MCF	7	1.00007	0.00265		7	0.99556	0.00196
MMM	1	1.00062			1	1.00106	
MMI	2	1.00806	0.00218		2	1.00466	0.00261
UMF	10	0.99827	0.00185		10	0.99755	0.00193
USI	33	0.98375	0.00563		33	0.98273	0.00575
UCT	9	0.99947	0.00206		9	0.99780	0.00186
UST	106	0.99989	0.00872		106	0.99807	0.00835
	1185	1.00040	0.00699		1177	0.99931	0.00669