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Initial ICSBEP Criticality Calculations with ENDF/B-VII.1β3 Cross Sections

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Abstract

We review MCNP eigenvalue calculations from a suite of International Criticality Safety Benchmark Evaluation Project (ICSBEP) Handbook evaluations with the recently distributed ENDF/B-VII.1β3 cross section library.

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ICSBEP Summary

- **HEU, IEU, LEU systems**
- **Pu systems**
- **Mixed systems**
- **^{233}U systems**
  - **Fast, Inter, Thermal energy ranges**
  - **Metal, Oxide, Solution fuel**
  - **Bare, Reflected**

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E71β3 File & NJOY Summary

- 418 evaluations in the ENDF/B-VII.1β3 file.
- Previous processing issues from the β2 file are now resolved
  - … but several evaluations need an ad-hoc patch in ACER to avoid plotting issues, ☹.
- All files processed to create MCNP ACE files with NJOY2010.
  - Still much data checking and comparing tbd.
  - NJOY sequence was MODER/RECONR/BROADR/UNRESR/HEATR(2)/THERMR/GASPR/PURR/ACER(2).
  - Independent files created by REM for his calculations.

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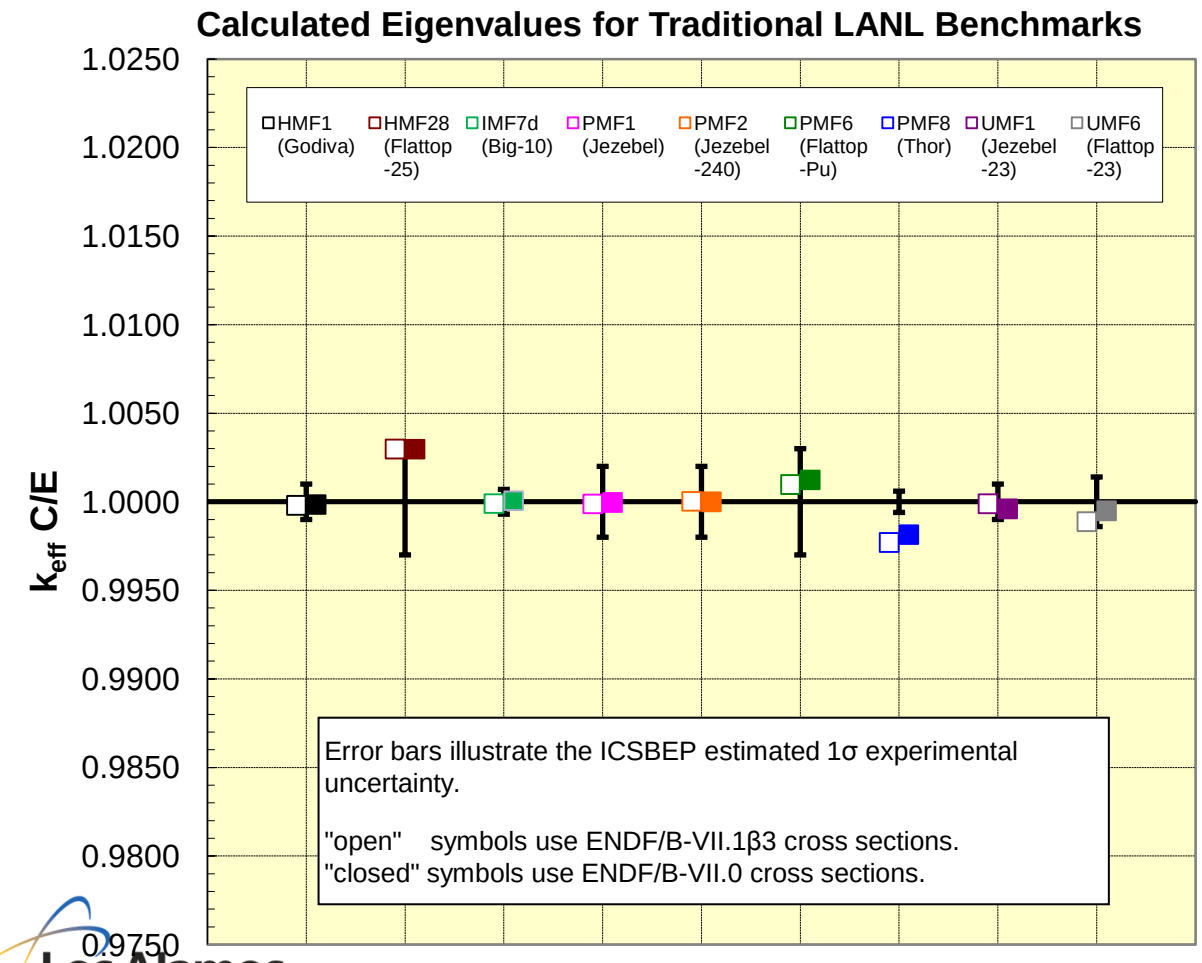
E71β3 File & NJOY Summary

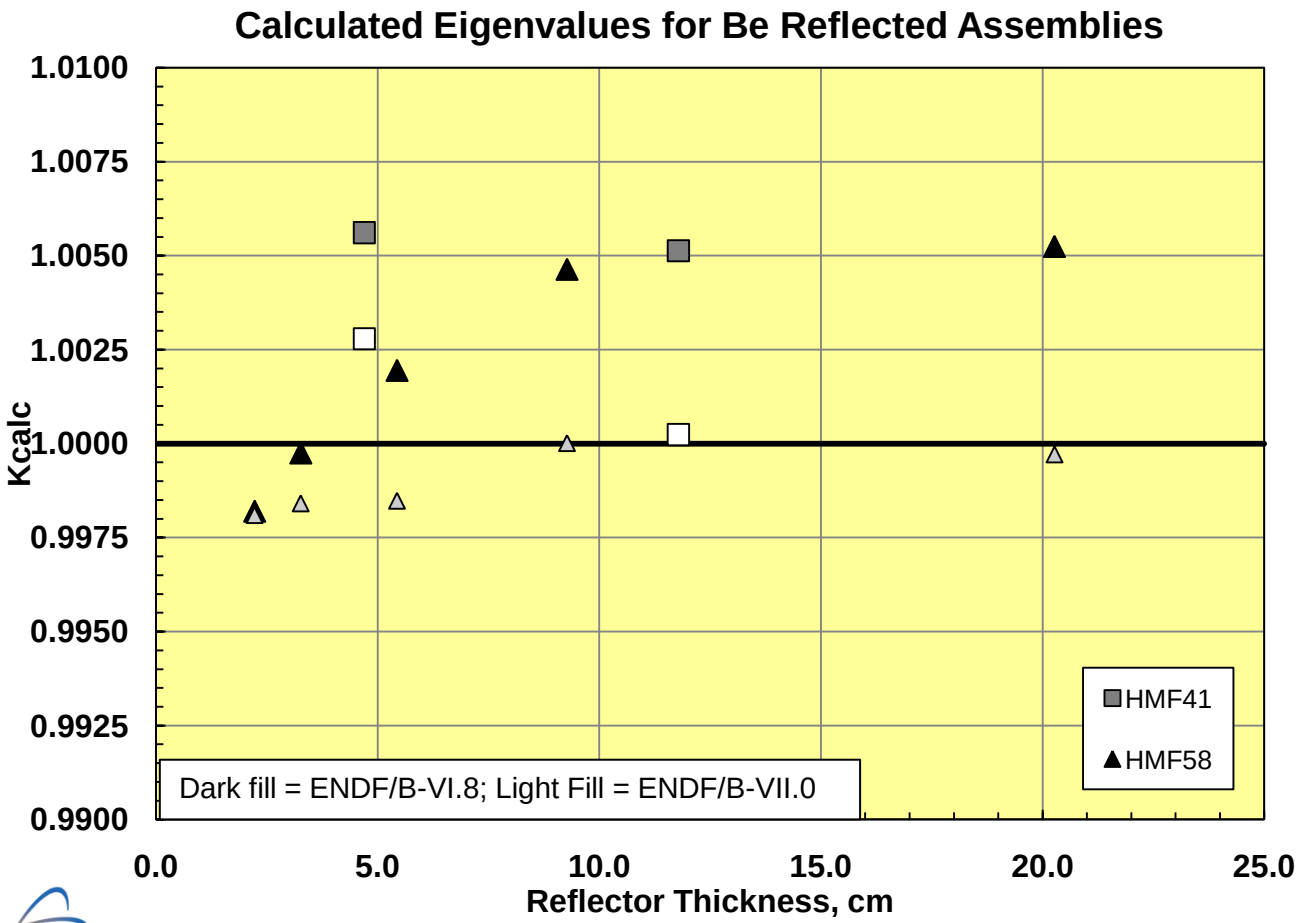
- Significant changes from ENDF/B-VII.0 to VII.1:
  - ^{9}Be, ^{16}O, ^{50,51}V, ^{46,47,48,49,50}Ti, ^{113}Cd, ^{155,157}Gd, ^{174,176,177,178,179,180}Hf, ^{180,182,183,184,186}W, ^{185,187}Re
    - ENDF/B-VII.0 has ^{nat}V.
    - ENDF/B-VII.0 omits ^{180}W.
    - Others discussed earlier yesterday and/or today.
    - Also show some ^{233}U results
      - Was the subject of an IAEA Consultants Meeting late last year.
      - Clear deficiencies exist in calculated eigenvalues for solution systems.

Traditional LANL Critical Assemblies



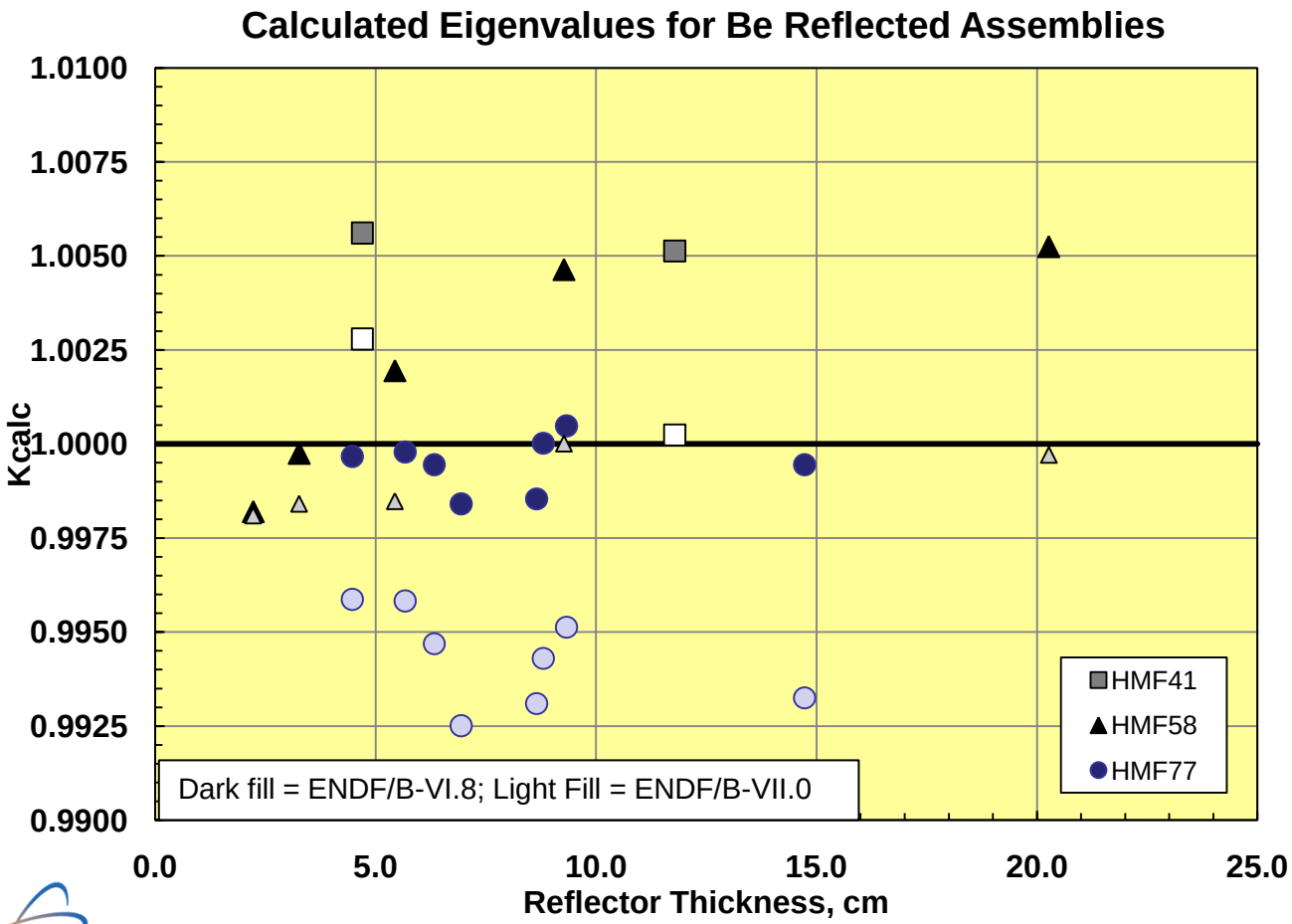
- Traditional LANL Assemblies
  - HEU, bare and reflected
  - Pu, bare and reflected
  - Heterogeneous uranium
  - ^{233}U, bare and reflected

^{9}Be



- LANL & LLNL experiments
- E68 k_{calc} biased high
- E70 k_{calc} is improved
- but …

^{9}Be

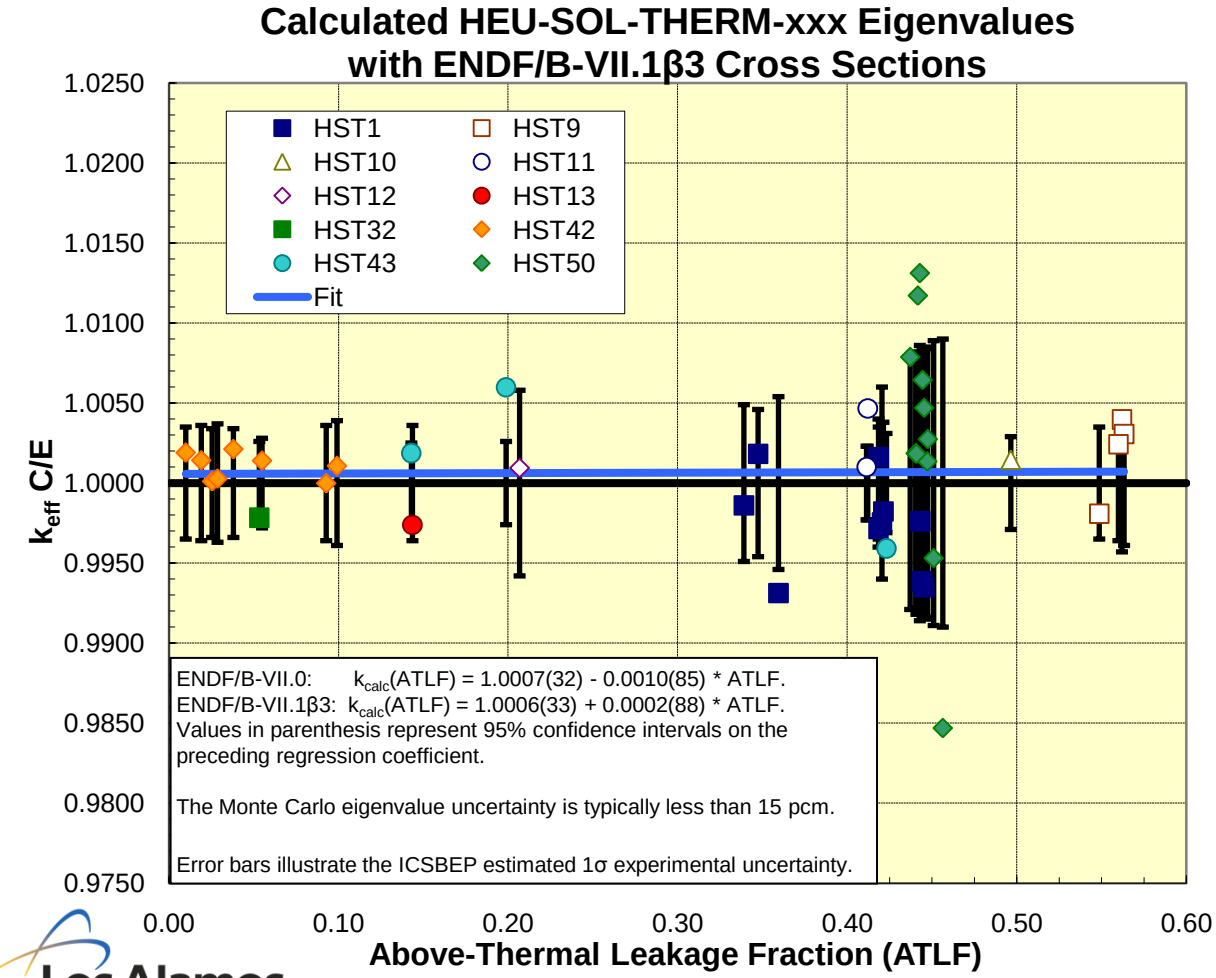


- HMF58 & 77 are LLNL experiments that use the same components!
- ENDF/B-VII.1β2 results move back toward ENDF/B-VI.8.

^{9}Be

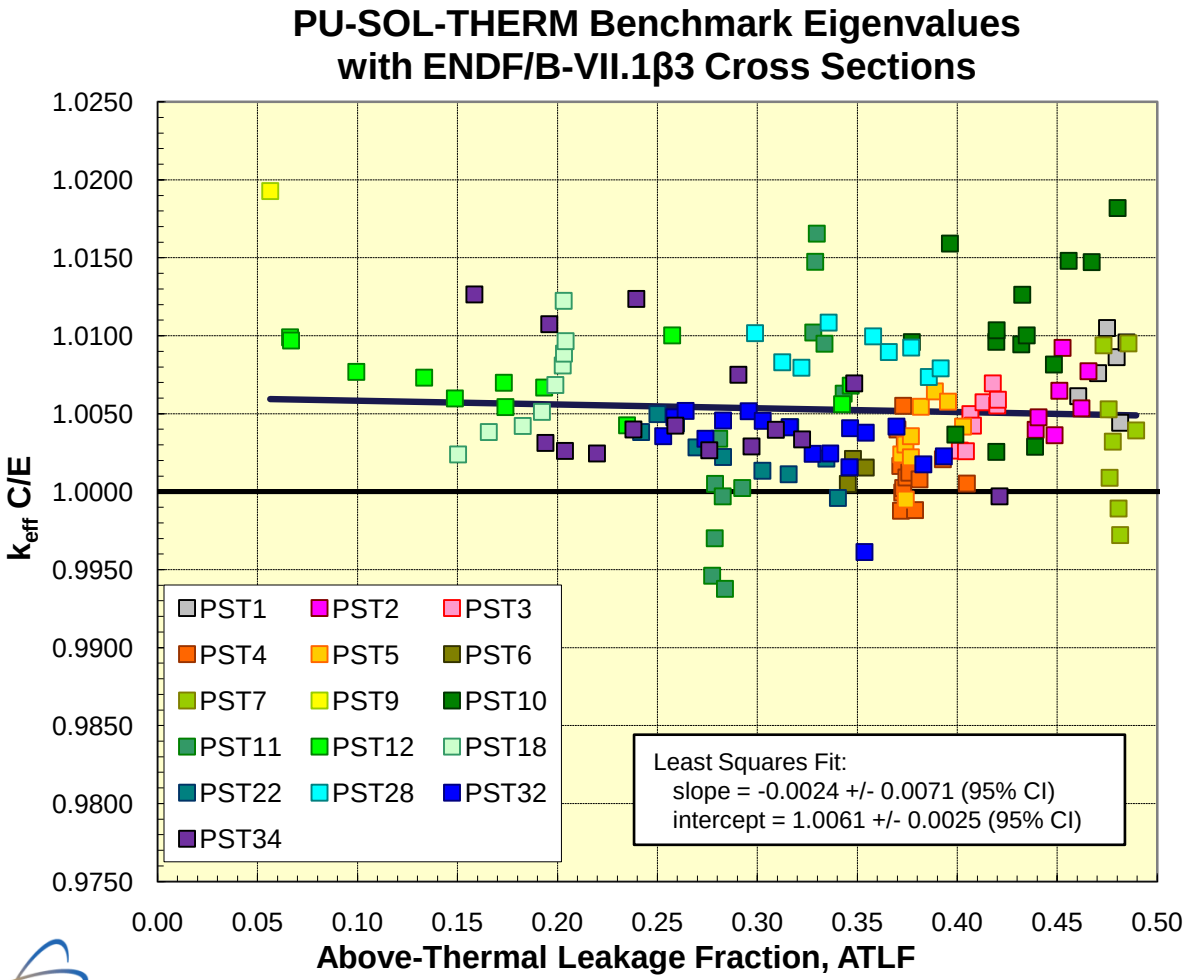
- Latest revision to the ^{9}Be file is believed to be fundamentally more correct.
- Impact of revised angular distributions remains to be assessed.
  - But an ad hoc change indicates that k_{calc} can vary significantly due to these data.
- Apparent discrepant critical experimental data are puzzling; a proposal for additional measurements at the Critical Experiments Facility (CEF) at NTSS has been accepted by the NCSP, but probably won't occur for a couple of years, ☹.

^{16}O



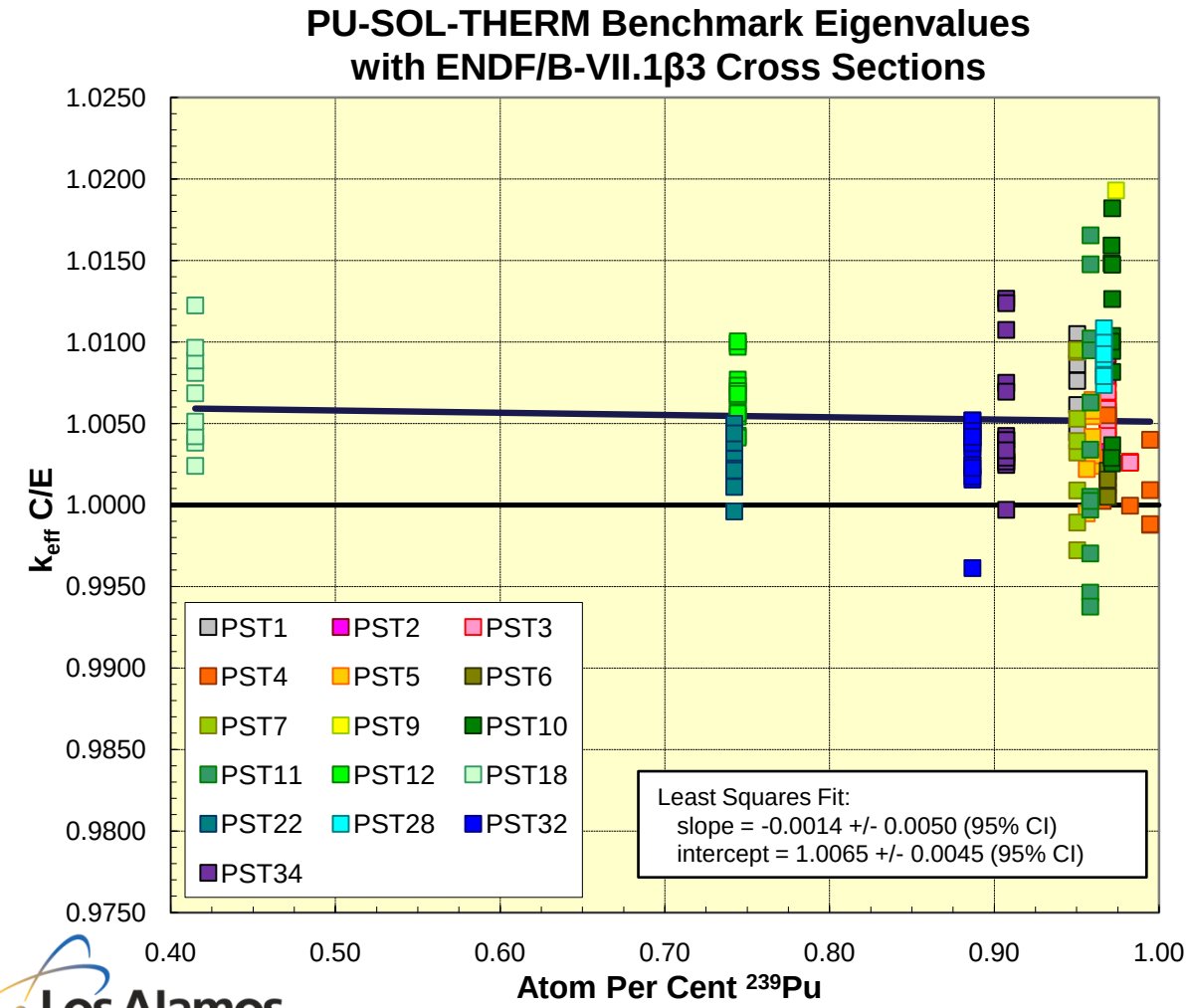
- Impact on HST eigenvalues is minimal.
- k_{calc} regression with ATLF retains near unity intercept and statistically insignificant slope.
- Similar result with β2 or β3 ^{16}O.
  - For β2 intercept is 1.0000(33); slope is +0.0029(88).

^{16}O



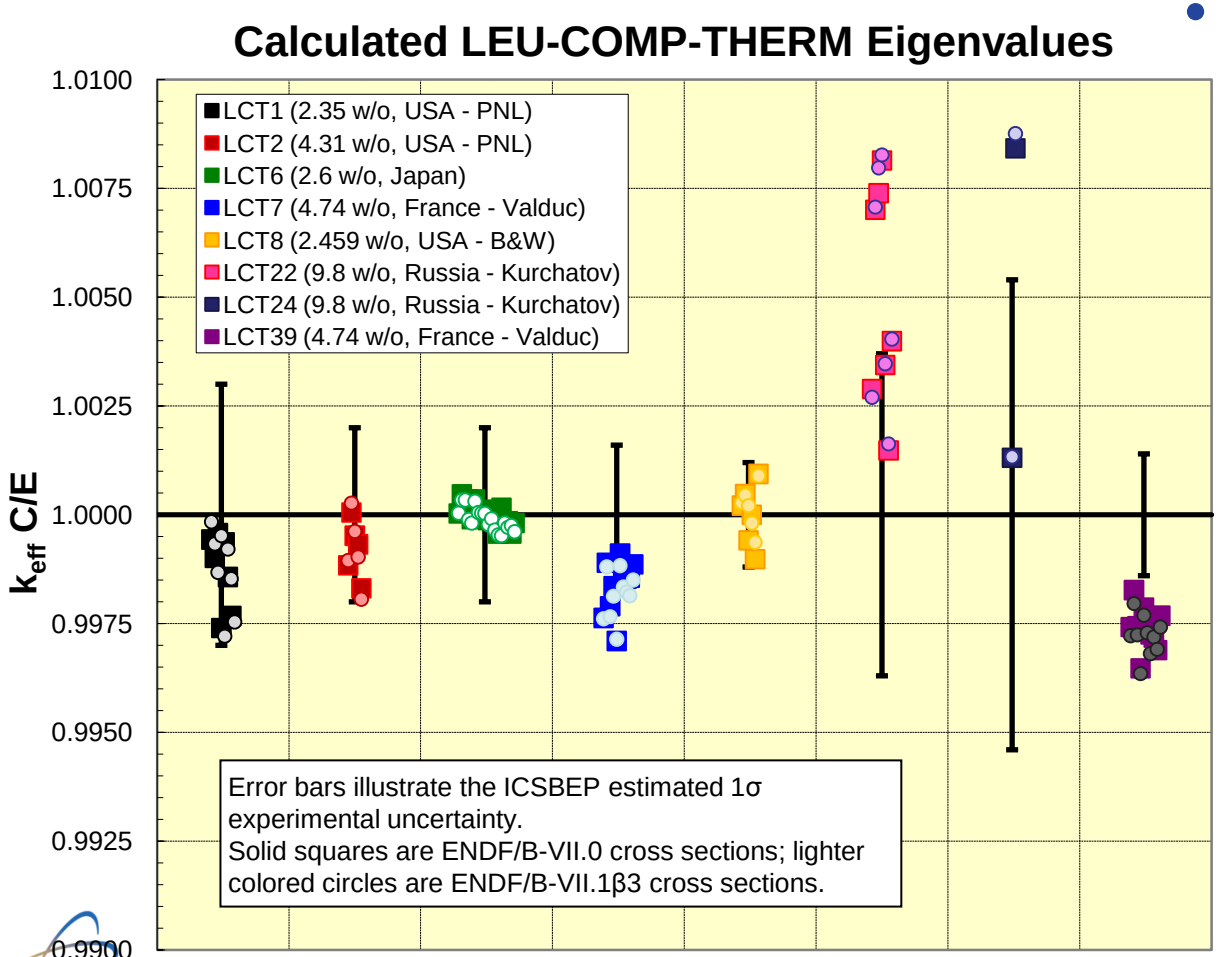
- PST benchmarks.
- No ATLF trend (same as HST).
- ^{239}Pu atom per-cent mostly >90%, but some at ~75% and ~40% (next figure).
- PST34 changes show impact of Gd revisions.

^{16}O



- PST benchmarks (con't).
- Tests for k_{calc} trend with
  - ATLF
  - ATFF
  - a/o ^{239}Pu
  - ^{239}Pu fission fract
  - Average fission E
  - Average lethargy
  - Grams pu/liter
  - ^{239}Pu/Pu capture
  - H capture
  - H/Pu ratio
  - No trend found

^{16}O



- Minimal change in LCT k_{calc}
  - Individual diffs up to ± 50 pcm; average diffs much smaller.

E71β3 – E70 (pcm):

- LCT1 (8): -16
- LCT2 (5): -2
- LCT6 (18): -10
- LCT7 (10): -23
- LCT8 (6): -17
- LCT22(7): +12
- LCT24(2): +18
- LCT25(4): +20
- LCT39(10): -19

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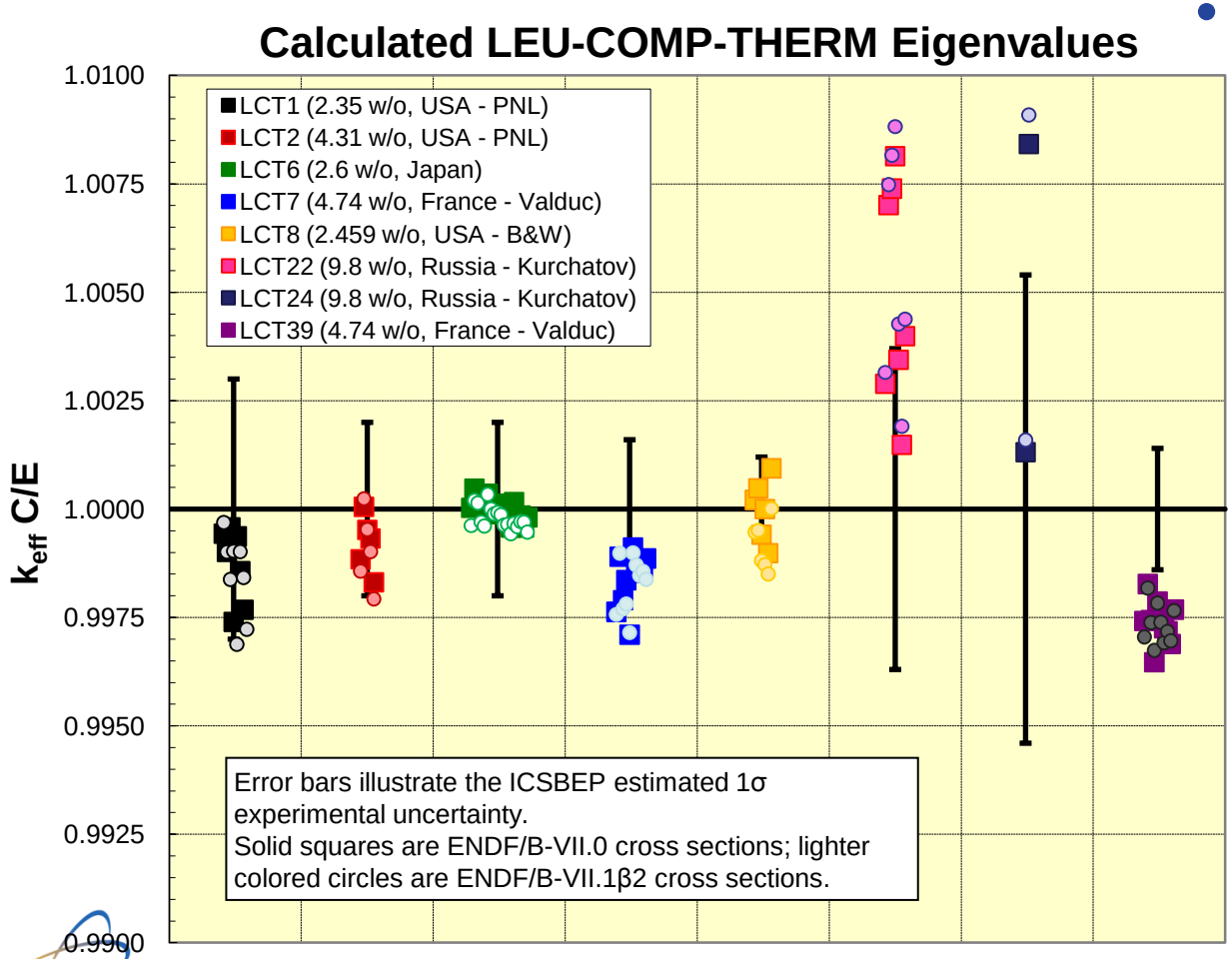
^{16}O



- Minimal change in LCT k_{calc}
  - LCT8, LCT25 show largest impact.

E71β2 – E70 (pcm):

- LCT1 (8): -43
- LCT2 (5): -15
- LCT6 (18): -21
- LCT7 (10): -14
- LCT8 (6): -83
- LCT22(7): +55
- LCT24(2): +48
- LCT25(4): +83
- LCT39(10): -6

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^{16}O

- Impact of revised ^{16}O evaluations are small
  - HST regression retains excellent near unity intercept and statistically insignificant slope with ATLF
    - β3 is slightly "better", but when values are statistically indistinguishable "better" may be in the eye of the beholder!
  - PST regression retains intercept bias, but near zero slope with various experimental and calculated parameters.
  - LCT eigenvalues typically change by less than ± 100 pcm
    - Change is often less than 25 pcm
    - ~ -80pcm for LCT8; ~ +80 pcm for LCT25 for b2
    - β3 differences are even smaller (as expected).
  - Seems like criticality testing can support either β2 or β3; knowing that further "Kadonis" tweaks remain to be added.
    - **NOTE: b3 may be e70, but different NJOY processing for (n,α) – mt107 versus sum of mt800 + mt801 now versus 2006.**

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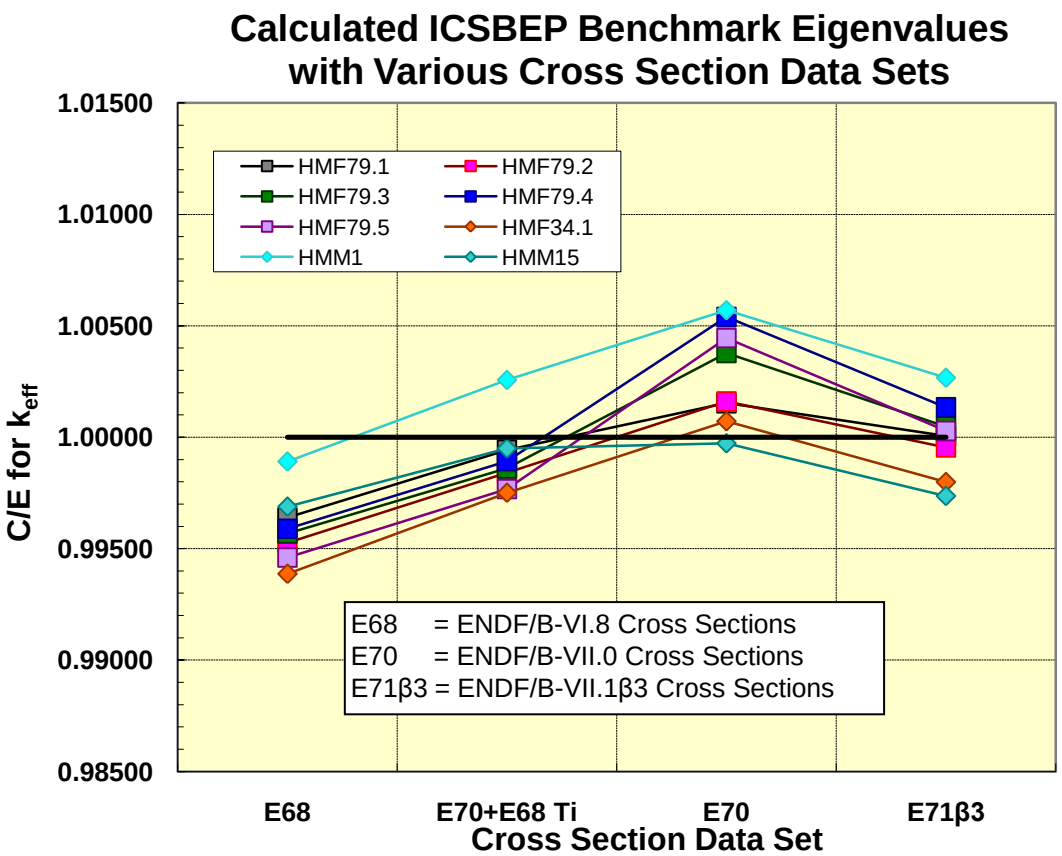
Data Testing: Ti and V Benchmarks

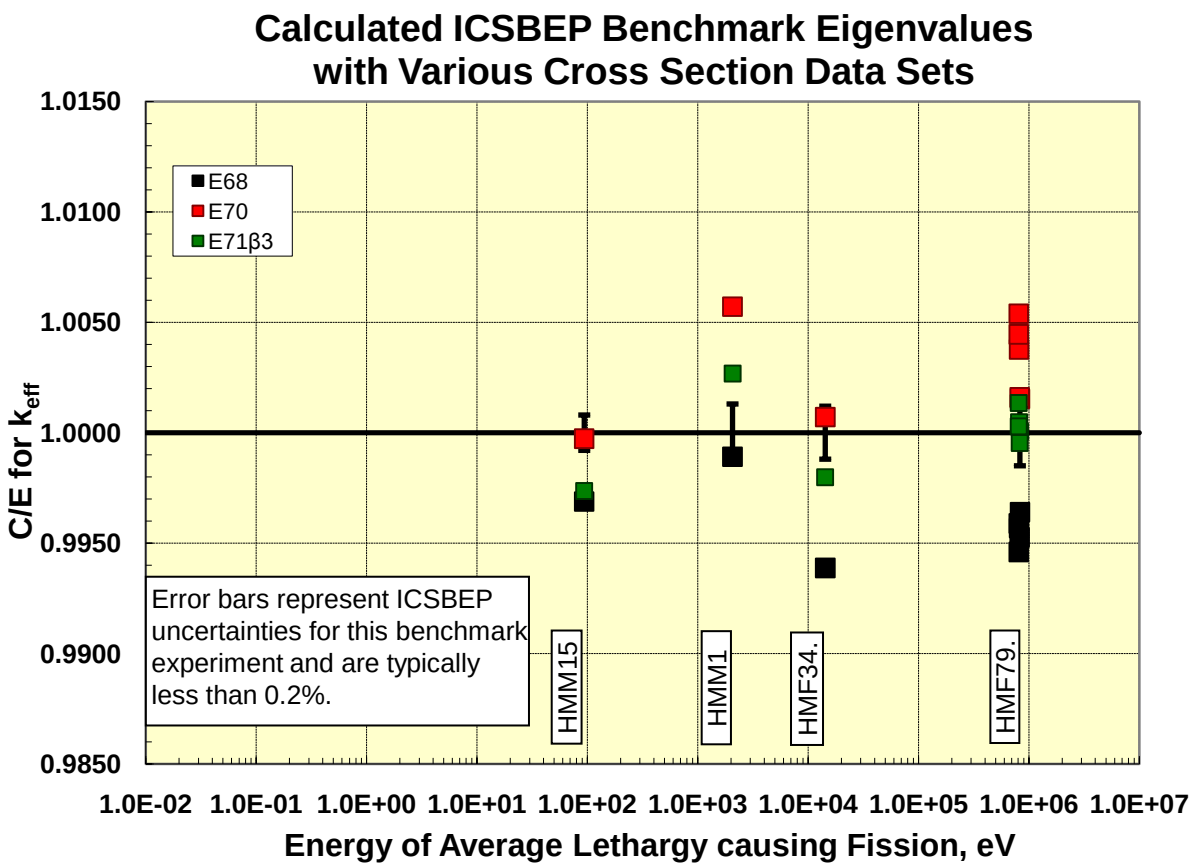
- Data Testing with ICSBEP Ti and V bearing benchmarks
  - Ti
    - HMF34 (case 1): interleaved HEU/Ti/Al.
    - HMF79: 5 cases with increasing axial reflector thickness.
    - HMM1: interleaved HEU/Ti/polyethylene plus a radial poly reflector.
    - HMM15: interleaved HEU/Ti/polyethylene plus a radial poly reflector.
  - V
    - HMF25: 5 cases with increasing axial reflector thickness.
    - HMF40: interleaved HEU/V.
    - HMM16: axial V with interleaved HEU/polyethylene.

^{46,47,48,49,50}Ti



- E68 is too cool.
- E70 is too hot.
- E71β3 is just right.

^{46,47,48,49,50}Ti



- No trend in calculated eigenvalues versus average fission energy.

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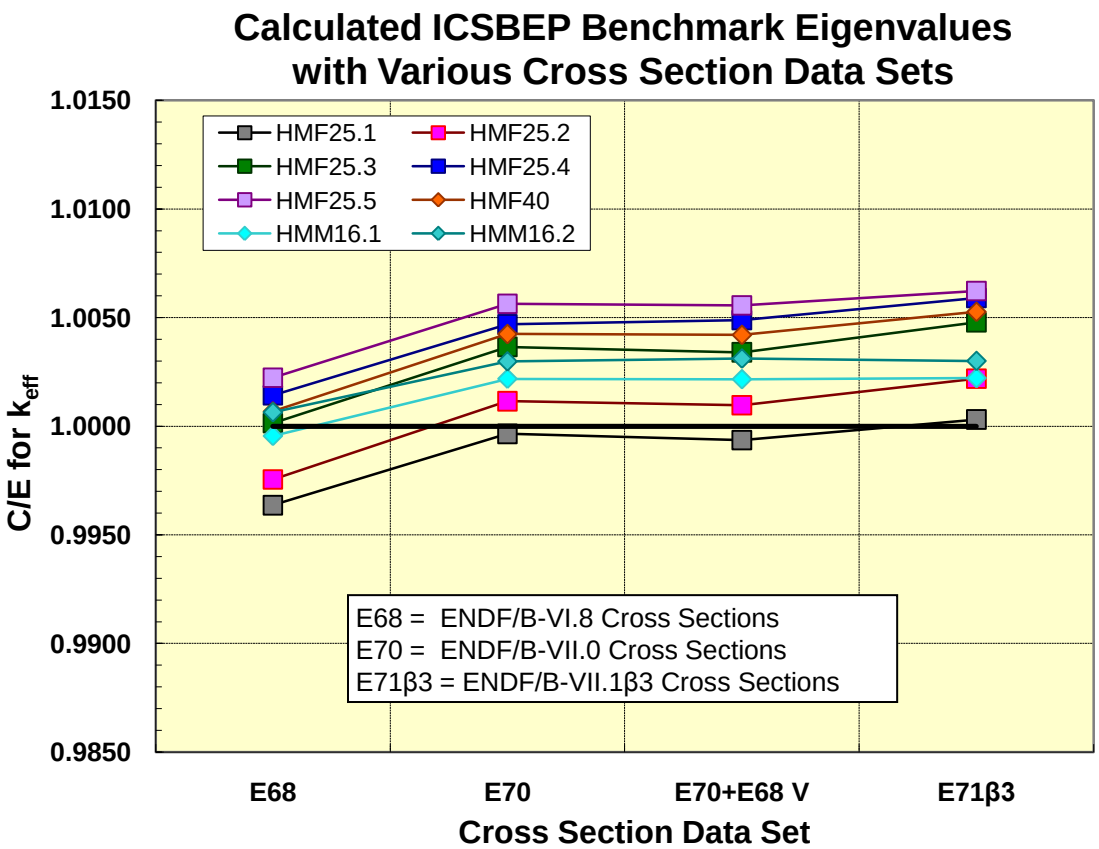
$^{50,51}V$

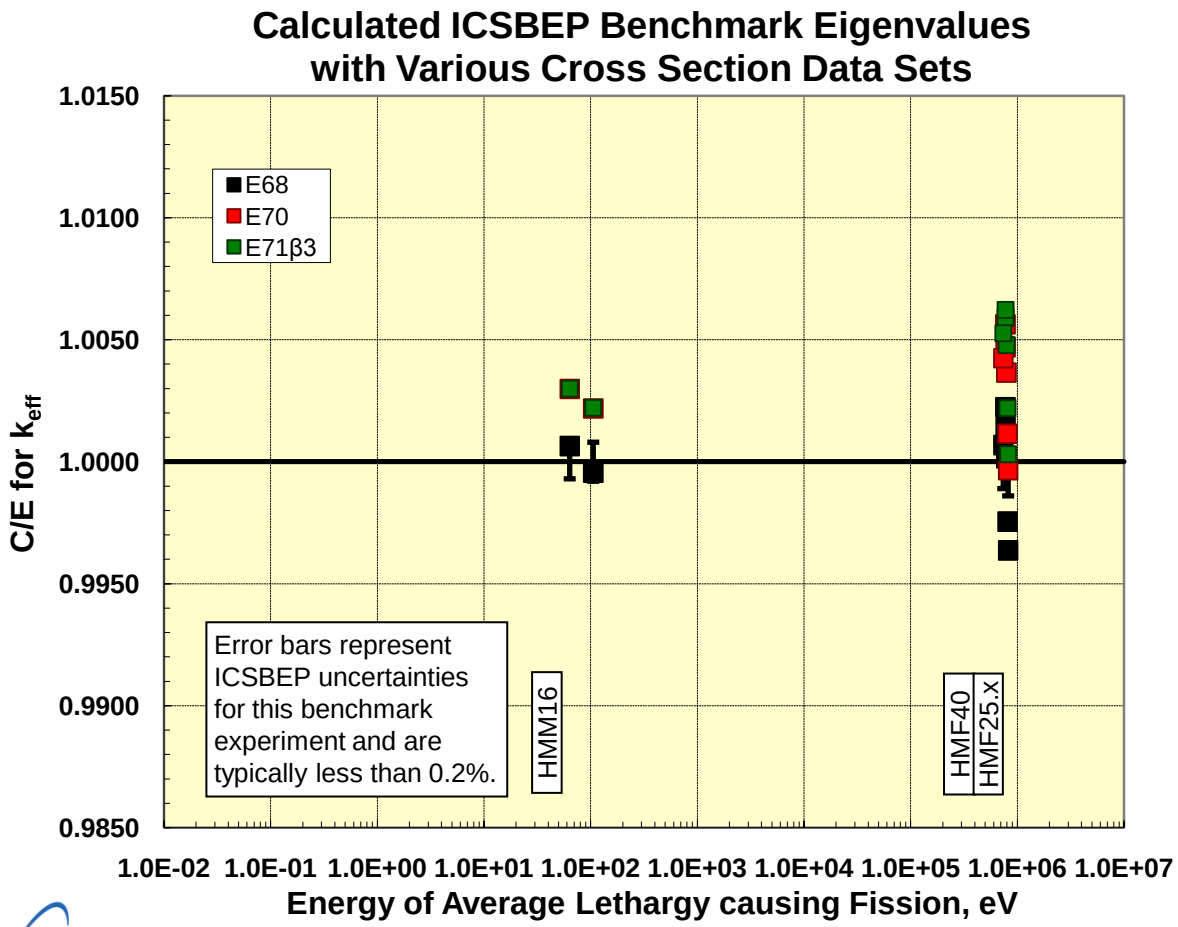
- $^{50,51}V$
  - Elemental ENDF/B-VII.0 evaluation will be replaced by isotopic evaluations; adopt JENDL-4 for ^{50}V; revised evaluation for ^{51}V.
- For ^{51}V:
  - Total Cross Section
    - 100 keV - 5 MeV adopt JENDL-4; above 5 MeV, optical model calculations using a modified Koning-Delaroche potential.
  - Reaction Cross Sections
    - all cross sections above 100 keV were evaluated consistently with the Hauser-Feshbach code CoH.
  - Scattering Angular Distributions
    - Retain elemental ENDF/B-VII.0 elastic scattering data
    - Use COH calculated results for inelastic levels.

$^{50,51}V$



- ENDF/B-VI.8 average is close to unity
- ENDF/B-VII.0 is biased high by several tenths of a percent
- Little change in k_{calc} with the latest ^{iso}V evaluated files.

$^{50,51}V$



- HMF25 results suggest trend with increasing axial reflector thickness.
- No trend in calculated eigenvalues with average fission energy, but data are limited.

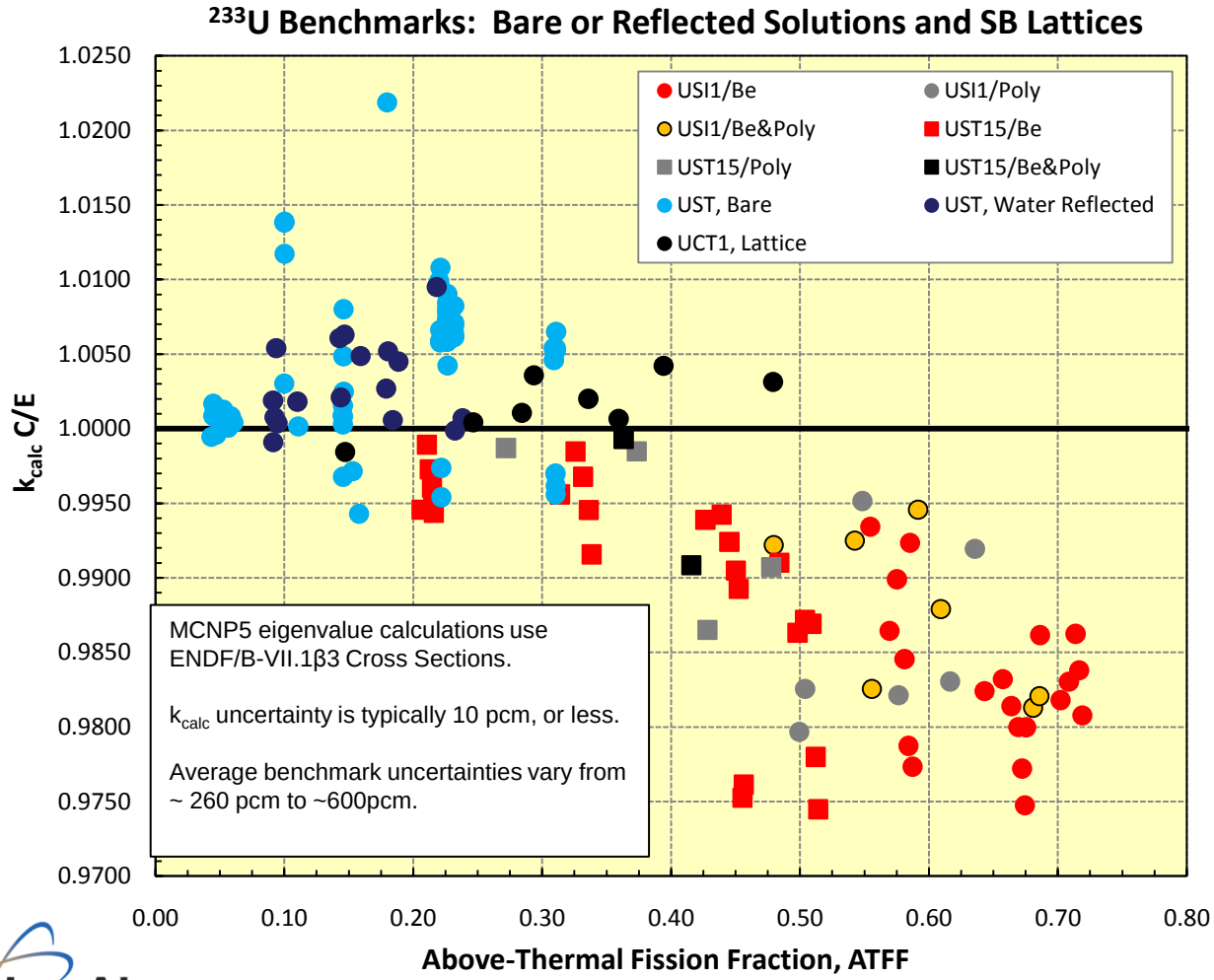
Data Testing: Ti and V Benchmarks

- Conclusions
  - Eigenvalues for Ti bearing benchmarks are calculated more accurately with the latest LANL generated isotopic Ti data files.
    - The increasing calculated eigenvalue trend introduced with the current ENDF/B-VII.0 isotopic Ti data sets has been significantly reduced.
  - ENDF/B-VII.0 V is a carryover from ENDF/B-VI, evaluated by ANL in the late 1980's, with minor revisions by BNL. These integral data testing results indicate that LANL's latest revisions have not eliminated the existing k_{calc} bias.

^{180,182,183,184,186}W

- Isotopic W Evaluations from the IAEA
  - Criticality testing to date
    - HMF3.8 to 3.11: 1.9" to 6.5" thick spherical reflector
    - HMF49.1 to 49.3: cylindrical geometry with 1 cm, 3 cm and 8 cm axial reflector
    - PMF5: 1.85" thick spherical reflector
    - UMF4.1, 4.2: 0.96" & 2.28" thick spherical reflector
- ENDF/B-VII.0 Calculated Eigenvalues are Too High
  - HMF3.8 - 3.11 = 1.00838(11), 1.00919(11), 1.01283(11) and 1.01685(10)
  - HMF49.1 – 49.3 = 1.0009(9), 1.0042(9), 1.0048(9)
  - PMF5 = 1.00947(10)
  - UMF4.1 – 4.2 = 1.00483(11), 1.00508(11)
- ENDF/B-VII.1β3 Calculated Eigenvalues are ~750 pcm Lower, but the Increasing Trend of k_{calc} with Increased Quantity of W Remains.
  - HMF3.8 – 3.11 = 1.00134(10), 1.00161(10), 1.00525(11) and 1.01000(11)
  - HMF49.1 – 49.3: 0.99799(9), 0.99961(9), 0.99844(16)
  - PMF5 = 1.00067(10)
  - UMF4.1 – 4.2 = 0.99890(11), 0.99603(11)
    - These new evaluations represent a significant improvement over ENDF/B-VII.0.

^{233}U Solutions



- H_2O, CH_2 and Be reflectors
- Results in a large ATFF interval.
- Mostly small (< 20pcm) increase compared to E70.
- β2 yields a further small k_{calc} increase.
- Not news, but something isn't right!

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ANL (ZPR) Criticals (per Bob MacFarlane)

ENDF/B-VII.1β2 and β3 results:

Assembly	Model-k	VII-k	1beta2	1beta3	C/E	Info
HMF047s	1.0007(37)	1.00166(11)	1.00213(11)		1.00143	Zeus/Nb-Zr/poly, bare
HMF055s	0.9955(28)	0.99876(10)	0.99832(10)		1.00283	U-Al/U (ZPR3-23 simp)
HMF055d	1.0013(20)	1.00396(12)	1.00343(12)		1.00213	(ZPR3-23 as built)
HMF060s	0.9955(24)	1.01563(11)	1.00268(11)		1.00721	U/W-Al ZPR-9/4
HMF060d	1.0013(11)	1.02070(11)	1.00848(11)		1.00717	(ZPR-9/4 as built)
HMF061s	0.9998(25)	1.00618(12)	1.00502(11)		1.00956	U/Graphite (ZPPR-21f)
HMF061d	1.0006(18)	1.00431(13)	1.00257(14)		1.00197	(ZPPR-21f as built)
HMF067-1s	0.9959(24)	1.00936(11)	1.00291(11)		1.00704	W-C-Al/Al (ZPR-9/5s)
HMF067-1d	1.0023(11)	1.01604(12)	1.00852(12)		1.00621	(ZPR-9/5 as built)
HMF072-1d	1.0000	1.00890(09)	1.00874(09)		1.00874	HEU/iron/Cu (Zeus)
PMF033s	0.9967(26)	0.99843(14)	0.99681(14)		1.00011	Pu/Graph (ZPPR-21A si)
PMF033d	1.0023(15)	1.00266(13)	1.00097(14)		0.99867	(ZPPR-21A as built)
MMF013s	0.9999(26)	1.00058(09)	1.00073(09)	1.00067(09)	1.00077	Pu core, HEU shells
IMF010s	0.9954(24)	0.99647(10)	0.99622(09)	0.99624(09)	1.00084	U9 (ZPR-6/9 simp)
IMF010d	1.0014(12)	1.00287(10)	1.00266(10)		1.00126	(ZPR-6/9 as built)
IMF012s	1.0007(27)	1.00348(10)	1.00301(10)	1.00329(10)	1.00259	U16 (ZPR-3/41 simp)
IMF012d	1.0014(18)	1.00325(11)	1.00294(11)		1.00154	(ZPR-3/41 as built)
IMF013s	0.9941(23)	0.99721(10)	0.99725(10)	0.99721(10)	1.00313	U11/Al (ZPR-9/1 simp)
IMF013d	1.0022(10)	1.00433(11)	1.00410(11)		1.00190	(ZPR-9/1 as built)
ICF001s	0.9939(23)	0.99319(10)	0.98975(10)	0.99285(10)	0.99894	U/U (ZPR6-6A)
ICF001d	1.0017(09)	0.99824(10)	0.99486(11)		0.99317	(ZPR6-6A as built)
MCF001s	0.9866(23)	0.98781(10)	0.98563(10)	0.98751(10)	1.00092	Pu/U (ZPR6-7)
MCF001d	1.0006(09)	1.00594(10)	1.00346(10)		1.00286	(ZPR6-7 as built)
HMI001s	0.9966(26)	1.00802(13)	1.00135(13)	1.00107(13)	1.00449	U/Fe (ZPR-9/34 simp)
PMI002d	1.0016(13)	1.02699(15)	1.01551(14)	1.01481(15)	1.01319	Pu/C/SSt (ZPR-6/10)