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**IAEA**

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# **Benchmarking IAEA CIELO evaluations of $n + {}^{235,238}\text{U}$**

**Andrej Trkov**

**Nuclear Data Section**

**International Atomic Energy Agency**

**Department for Nuclear Sciences and Applications**

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# IAEA CIELO evaluations: $n + {}^{235,238}\text{U}$

## ${}^{235}\text{U}$

- ❑ ENDF/B-VIII.β3 = ENDF/B-VIII.β2 (IAEA u238-b18)
- ❑ ENDF/B-VIII.β4 = IAEA u235-b36 ... (prelim. STD)
- ❑ ENDF/B-VIII.postβ4 = IAEA u235-b46... (STD 2017)

## ${}^{238}\text{U}$

- ❑ ENDF/B-VIII.β3 = ENDF/B-VIII.β2 (IAEA u238-b46)
- ❑ ENDF/B-VIII.β4 = IAEA u238-b51 ... (prelim. STD)
- ❑ ENDF/B-VIII.postβ4 = IAEA u238-b58 ... (STD 2017)

# Scope

## First round:

- Consistency with differential data from EXFOR
- Consistency with spectrum-averaged cross sections, where applicable

## Next round (focus of this presentation)

- Criticality benchmarks from ICSBEP
- LLNL pulsed sphere experiments
- (RPI quasi-differential benchmark)
- Other ...

# ICSBEF Categories

- “**u235\_bare**” – bare critical assemblies of highly-enriched uranium
- “**main**” – a collection of frequently used fast benchmarks
- “**u235\_ATLF**” – highly-enriched uranium solutions v.s. above-thermal leakage fraction
- “**u235\_bad\_f**” – short list of problematic fast benchmarks that originally performed worse than ENDF/B-VII.1
- “**u235\_bad\_t**” – short list of problematic thermal benchmarks that originally performed worse than ENDF/B-VII.1
- “**Mosteller suite**” - broad-scope benchmarking
- Other ...

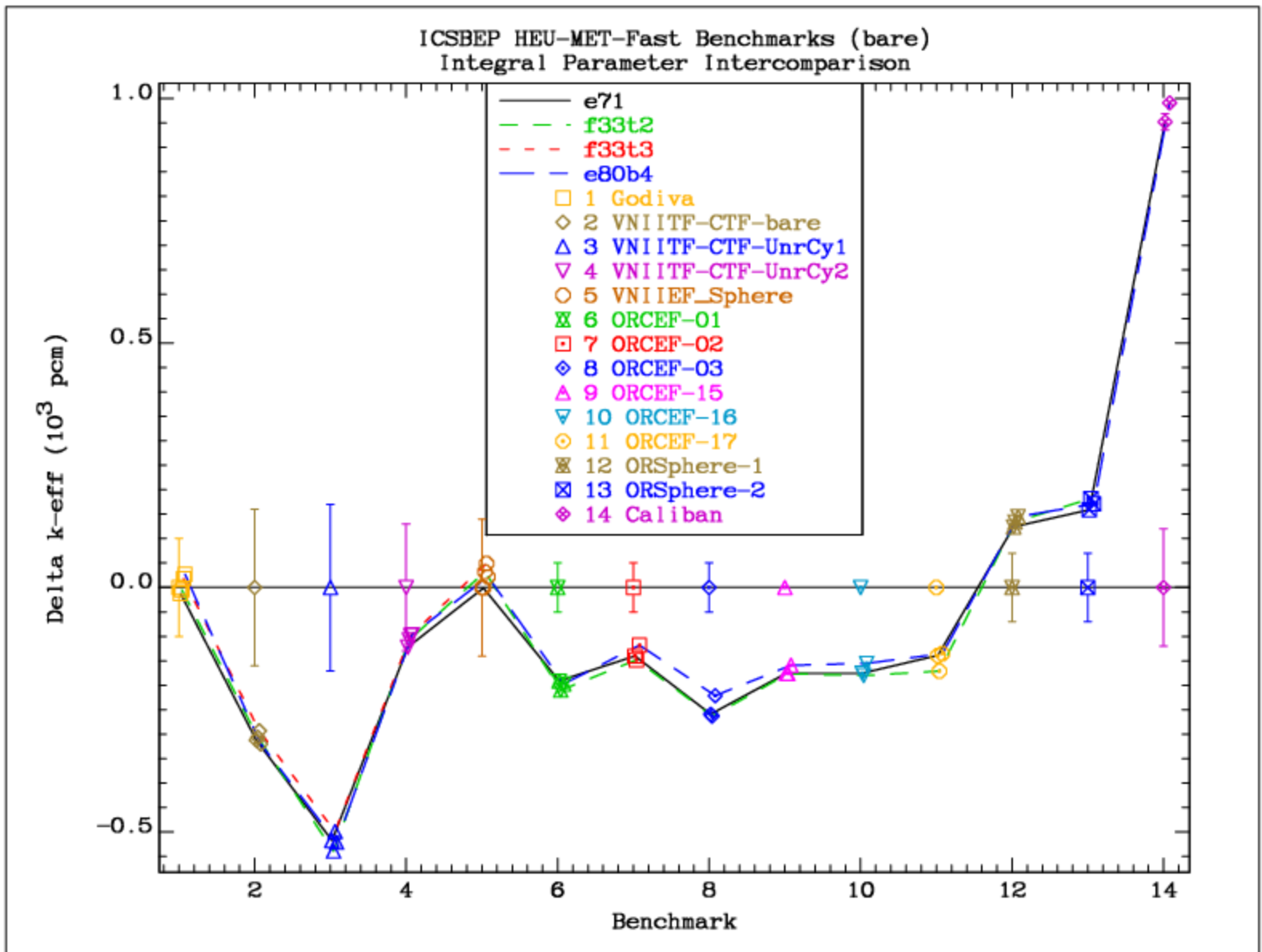
# Libraries

- “**e71**” – ENDF/B-VII.1
- “**f33T2**” – JEFF-3.3 test library Version-2
- “**f33T3**” – JEFF-3.3 test library Version-3
- “**e80b4**” – IAEA-CIELO evaluations within the ENDF/B-VIII beta-4 library

(any additional suffix refers to small file modifications that do not affect benchmarking)

# Results: “u235\_bare”

	ICSBEP name	Short	Common name
1	HEU-MET-FAST-001	hmf001	Godiva
2	HEU-MET-FAST-008	hmf008	VNIIEF-CTF-bare
3	HEU-MET-FAST-015	hmf015	VNIIEF-CTF-UnrCy1
4	HEU-MET-FAST-065	hmf065	VNIIEF-CTF-UnrCy2
5	HEU-MET-FAST-018	hmf018	VNIIEF_Sphere
6	HEU-MET-FAST-051	hmf051-01	ORCEF-01
7	HEU-MET-FAST-051	hmf051-02	ORCEF-02
8	HEU-MET-FAST-051	hmf051-03	ORCEF-03
9	HEU-MET-FAST-051	hmf051-15	ORCEF-15
10	HEU-MET-FAST-051	hmf051-16	ORCEF-16
11	HEU-MET-FAST-051	hmf051-17	ORCEF-17
12	HEU-MET-FAST-100	hmf100-1	ORSphere-1
13	HEU-MET-FAST-100	hmf100-2	ORSphere-2
14	HEU-MET-FAST-080	hmf080	Caliban

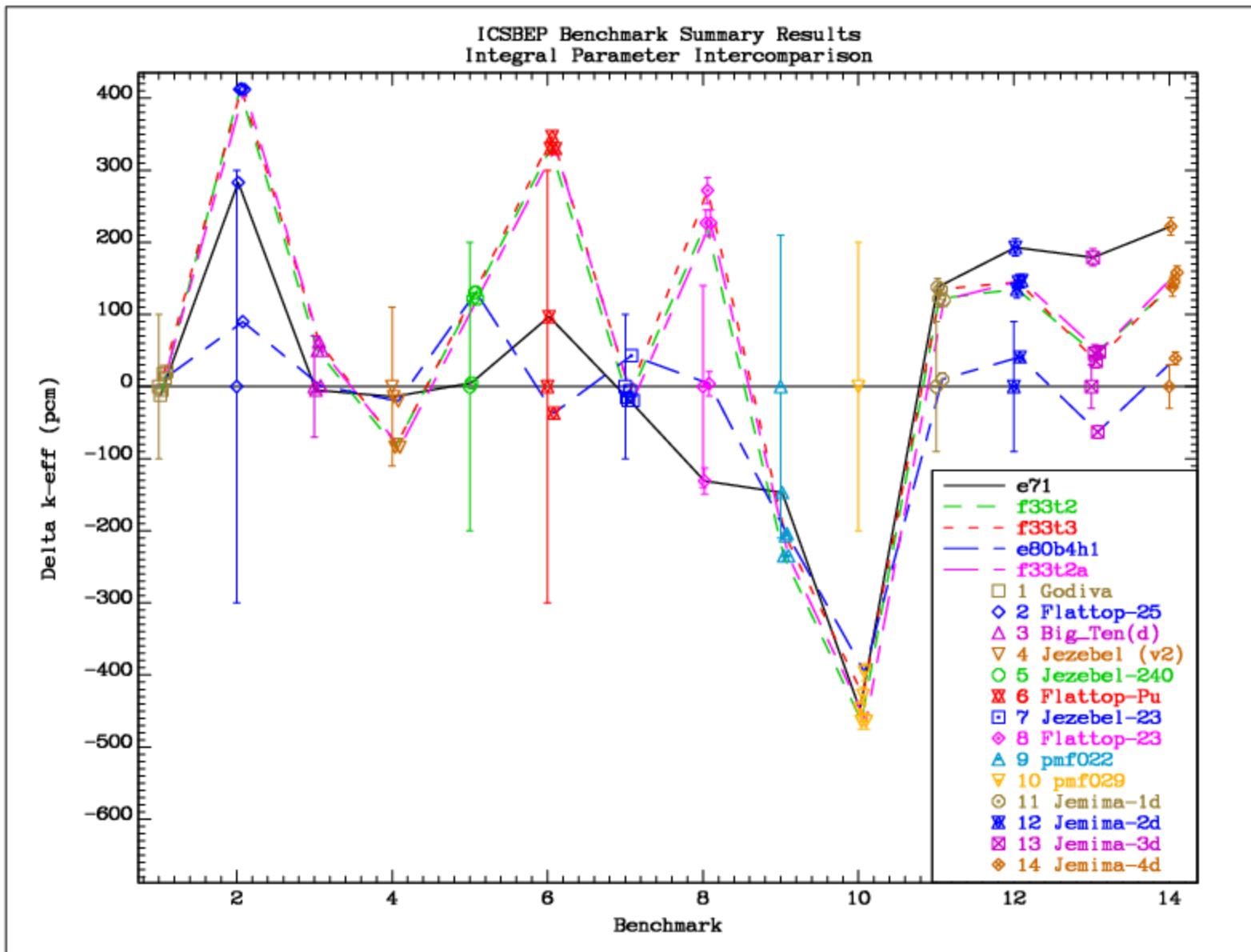


# Comments

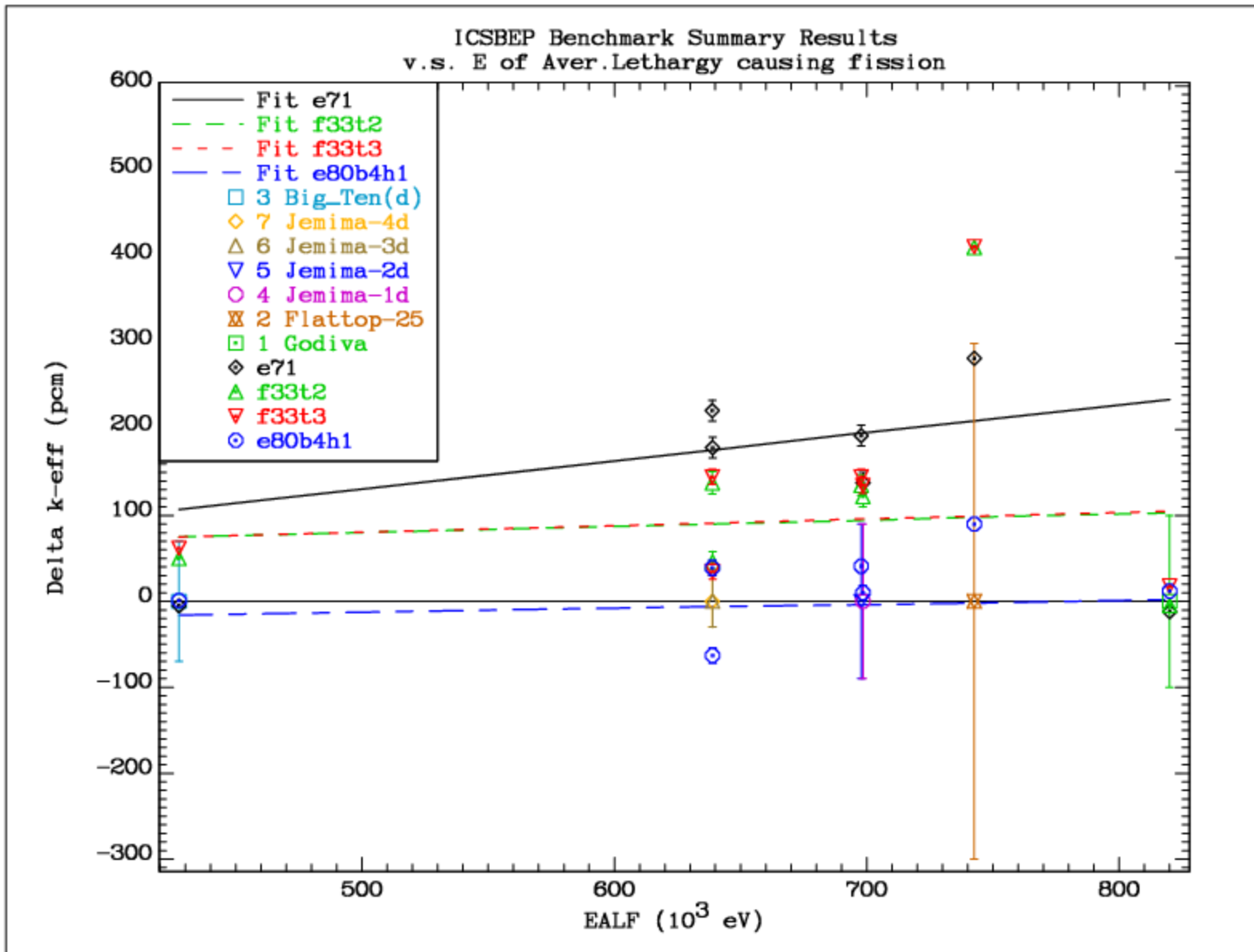
- Results are similar in spite of differences in data
- ~500 pcm spread in Russian benchmarks
- ~500 pcm spread in ORNL benchmarks
- ~1000 pcm discrepancy in the French Caliban!!!
  - Fissile material inventory inconsistency in benchmark specifications
  - Sensitivity to Mo insufficient to explain the discrepancy
  - Awaiting feedback from authors...

# Results: “main”

	ICSBEP name	Short	Common name
1	HEU-MET-FAST-001	hmf001	<b>Godiva</b>
2	HEU-MET-FAST-028	hmf028	<b>Flattop-25</b>
3	IEU-MET-FAST-007	imf007d	<b>Big_Ten(detailed)</b>
4	PU-MET-FAST-001	pmf001	Jezebel
5	PU-MET-FAST-002	pmf002	Jezebel-240
6	PU-MET-FAST-006	pmf006	Flattop-Pu
7	U233-MET-FAST-001	umf001	Jezebel-U233
8	U233-MET-FAST-006	umf006	Flattop-23
9	PU-MET-FAST-022	pmf022	Bare(98 a/o)
10	PU-MET-FAST-029	pmf029	Bare(88 a/o, No Pu-242)
11	IEU-MET-FAST-001	imf001-001d	<b>Jemima-1d</b>
12	IEU-MET-FAST-001	imf001-002d	<b>Jemima-2d</b>
13	IEU-MET-FAST-001	imf001-003d	<b>Jemima-3d</b>
14	IEU-MET-FAST-001	imf001-004d	<b>Jemima-4d</b>



ICSBEP Benchmark Summary Results  
v.s. E of Aver.Lethargy causing fission



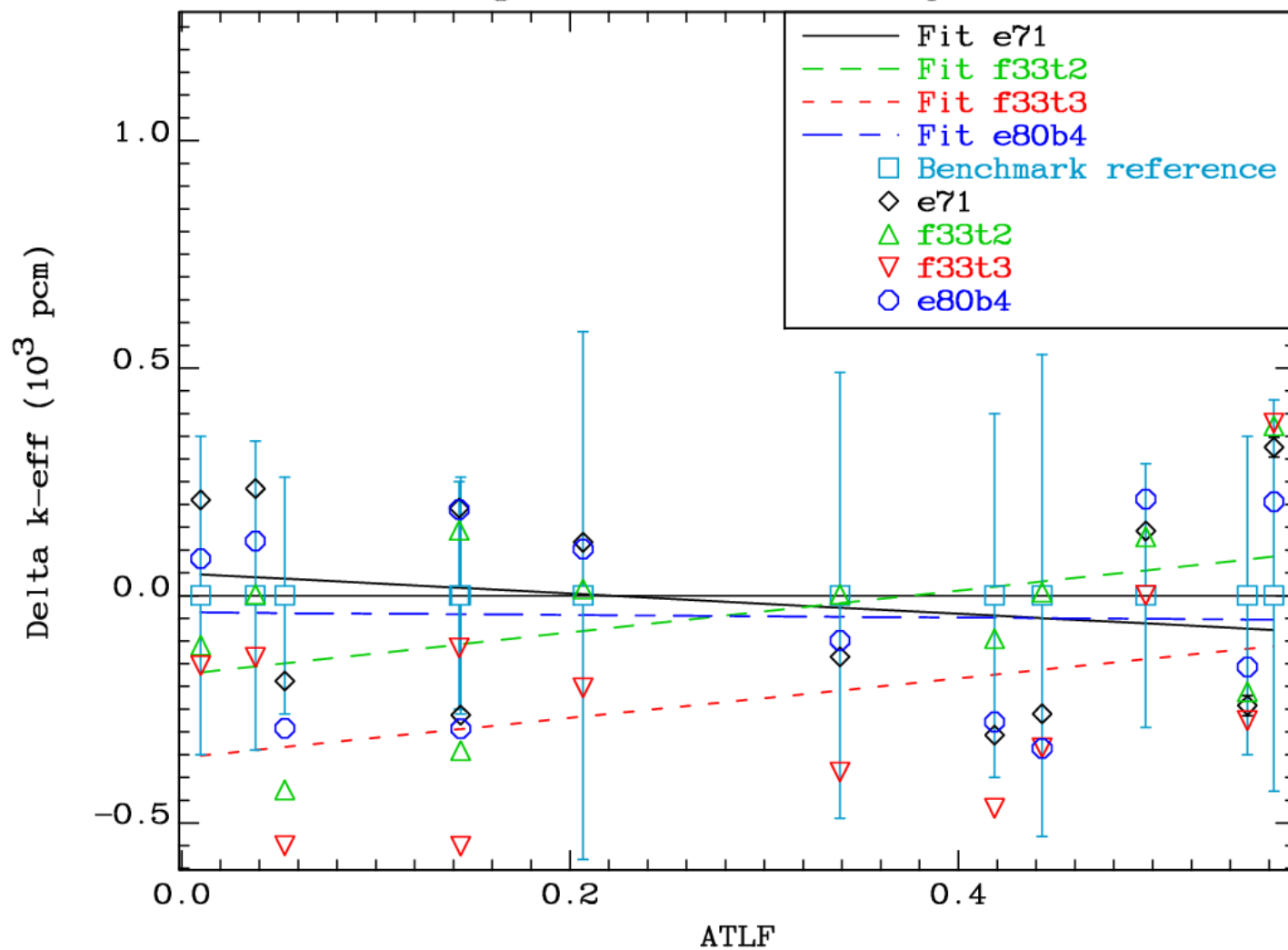
# Comments

- CIELO evaluations (label “e80b4”) greatly reduce the spread in the results
- No trend with “Energy of the average lethargy causing fission” (EALF)
- (pmf029 gives no information about  $^{242}\text{Pu}$  content ? And no detailed composition of impurities )

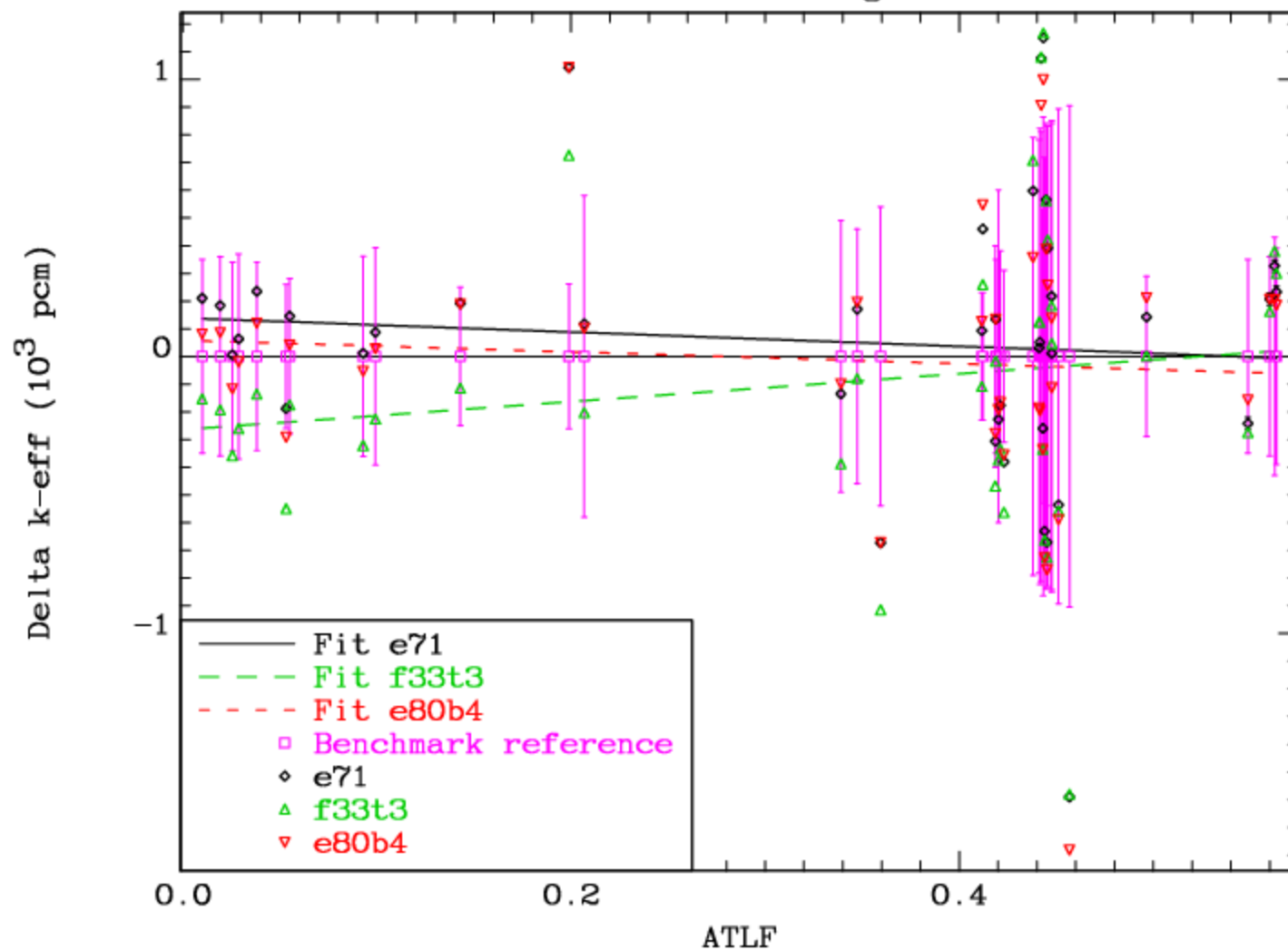
# Results: “u235\_ATLF”

	ICSBEP name	Short	Common name
1	HEU-SOL-THERM-009	hst009-001	ORNL_S1
2	HEU-SOL-THERM-009	hst009-004	ORNL_S4
3	HEU-SOL-THERM-013	hst013-001	ORNL_T1
4	HEU-SOL-THERM-032	hst032	ORNL_T5
5	HEU-SOL-THERM-001	hst001-004	R04
6	HEU-SOL-THERM-001	hst001-005	R05
7	HEU-SOL-THERM-001	hst001-007	R07
8	HEU-SOL-THERM-042	hst042-001	ORNL_C1
9	HEU-SOL-THERM-042	hst042-004	ORNL_C4
10	HEU-SOL-THERM-042	hst042-008	ORNL_C8
11	HEU-SOL-THERM-043	hst043-003	ORNL_LS3
12	HEU-SOL-THERM-010	hst010-001	ORNL_S10T0
13	HEU-SOL-THERM-012	hst012	ORNL_S91

ICSBEF Benchmark Summary Results  
Integral Parameter Intercomparison



ICSBEF HEU-SOL-THERM Benchmarks (42)  
v.s. Above Thermal Leakage Fraction



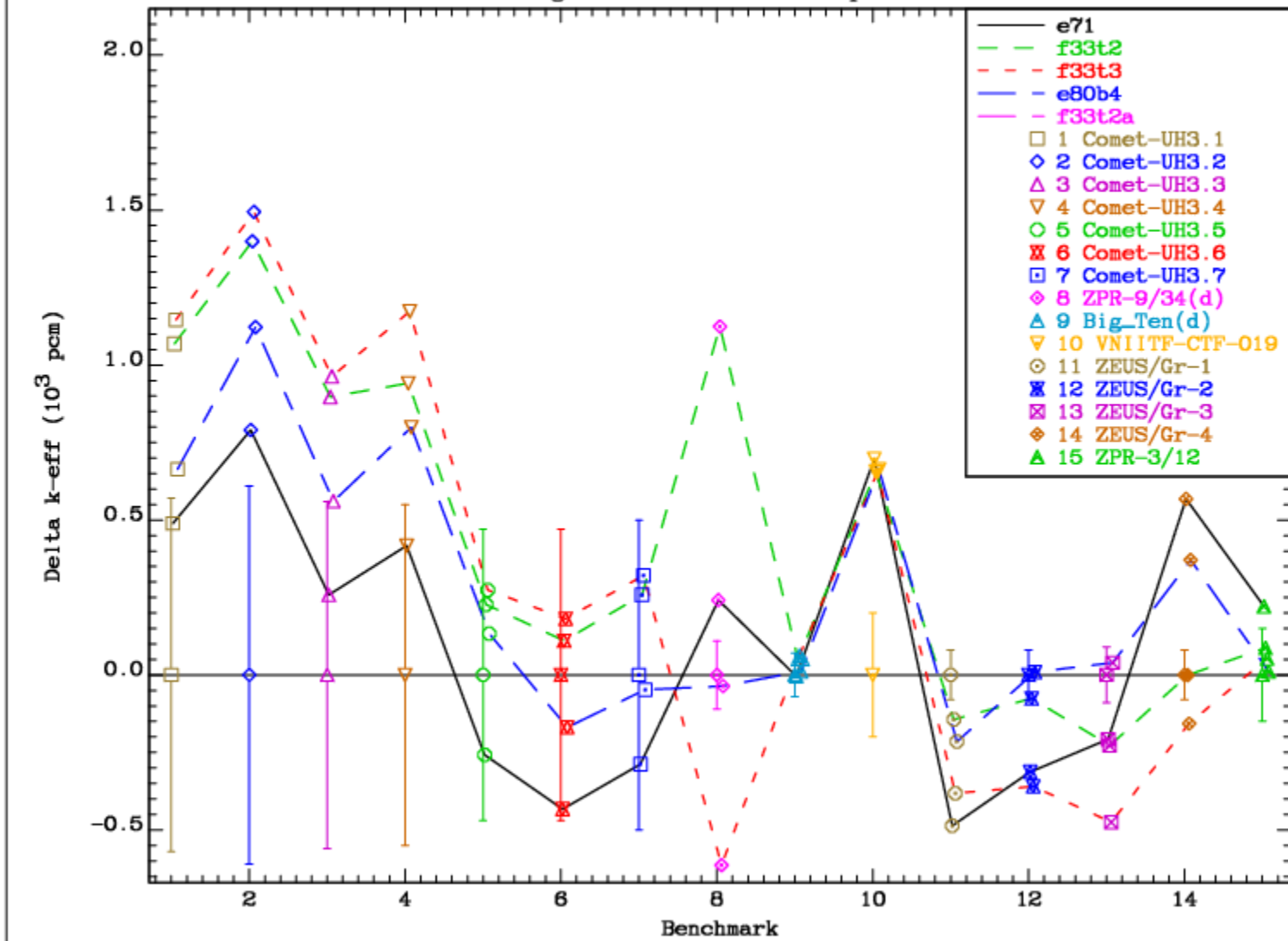
# Comments

- The short list is representative of the long list
- There exist other benchmark involving solutions
  - Caution – some will be revised (eg: hst048)

# Problematic cases “u235\_bad\_f”

	ICSBEP name	Short	Common name
1	HEU-COMP-INTER-003	hci003-001	COMET-UH3-1
2	HEU-COMP-INTER-003	hci003-002	COMET-UH3-2
3	HEU-COMP-INTER-003	hci003-003	COMET-UH3-3
4	HEU-COMP-INTER-003	hci003-004	COMET-UH3-4
5	HEU-COMP-INTER-003	hci003-005	COMET-UH3-5
6	HEU-COMP-INTER-003	hci003-006	COMET-UH3-6
7	HEU-COMP-INTER-003	hci003-007	COMET-UH3-7
8	HEU-MET-INTER-001	hmi001d	ZPR-9/34(detailed)
9	IEU-MET-FAST-007	imf007d	Big_Ten(detailed)
10	HEU-MET-FAST-019	hmf019	CNIITF-CTF-019
11	HEU-MET-INTER-006	hmi006-001	Zeus-1/Gr
12	HEU-MET-INTER-006	hmi006-002	Zeus-2/Gr
13	HEU-MET-INTER-006	hmi006-003	Zeus-3/Gr
14	HEU-MET-INTER-006	hmi006-004	Zeus-4/Gr
15	IEU-COMP-FAST-004	icf004	ZPR-3/12

ICSBEP Benchmark Summary Results  
Integral Parameter Intercomparison



# Comments

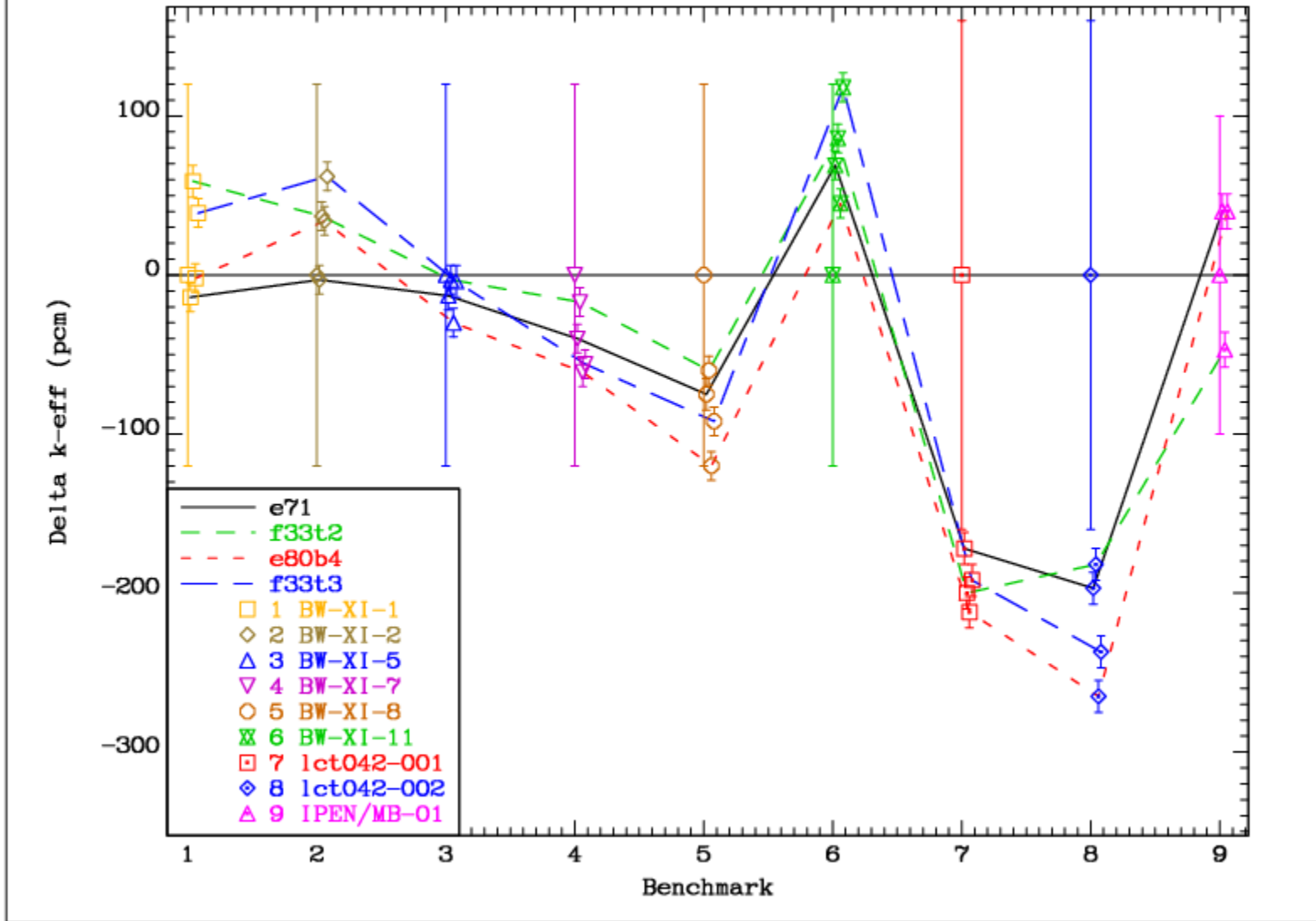
Cases where previously some problems with IAEA-CIELO evaluations were encountered:

- Not perfect, some cases slightly worse than ENDF/B-VII.1, similar to JEFF-3.3
- Zeus benchmarks are somewhat better with JEFF-3.3T2; with JEFF-3.3T3 they are systematically low, but have no gradient

# Problematic cases “u235\_bad\_t”

	ICSBEP name	Short	Common name
1	LEU-COMP-THERM-008	lct008-001	BW-XI-1
2	LEU-COMP-THERM-008	lct008-002	BW-XI-2
3	LEU-COMP-THERM-008	lct008-005	BW-XI-5
4	LEU-COMP-THERM-008	lct008-007	BW-XI-7
5	LEU-COMP-THERM-008	lct008-008	BW-XI-8
6	LEU-COMP-THERM-008	lct008-011	BW-XI-11
7	LEU-COMP-THERM-042	lct042-001	lct042-001
8	LEU-COMP-THERM-042	lct042-002	lct042-002
9	LEU-COMP-THERM-043	lct043-002	IPEN/MB-01

ICSBEP Benchmark Summary Results  
Integral Parameter Intercomparison



# Comments

Cases where previously some problems with IAEA-CIELO evaluations were encountered:

- Not perfect, some cases slightly worse than ENDF/B-VII.1, similar to JEFF-3.3
- Some benchmarks are slightly better with JEFF-3.3T2; with JEFF-3.3T3 they are systematically higher than IAEA-CIELO, but with similar trends

# Broad Scope Benchmarking

## LANL Mosteller Suite

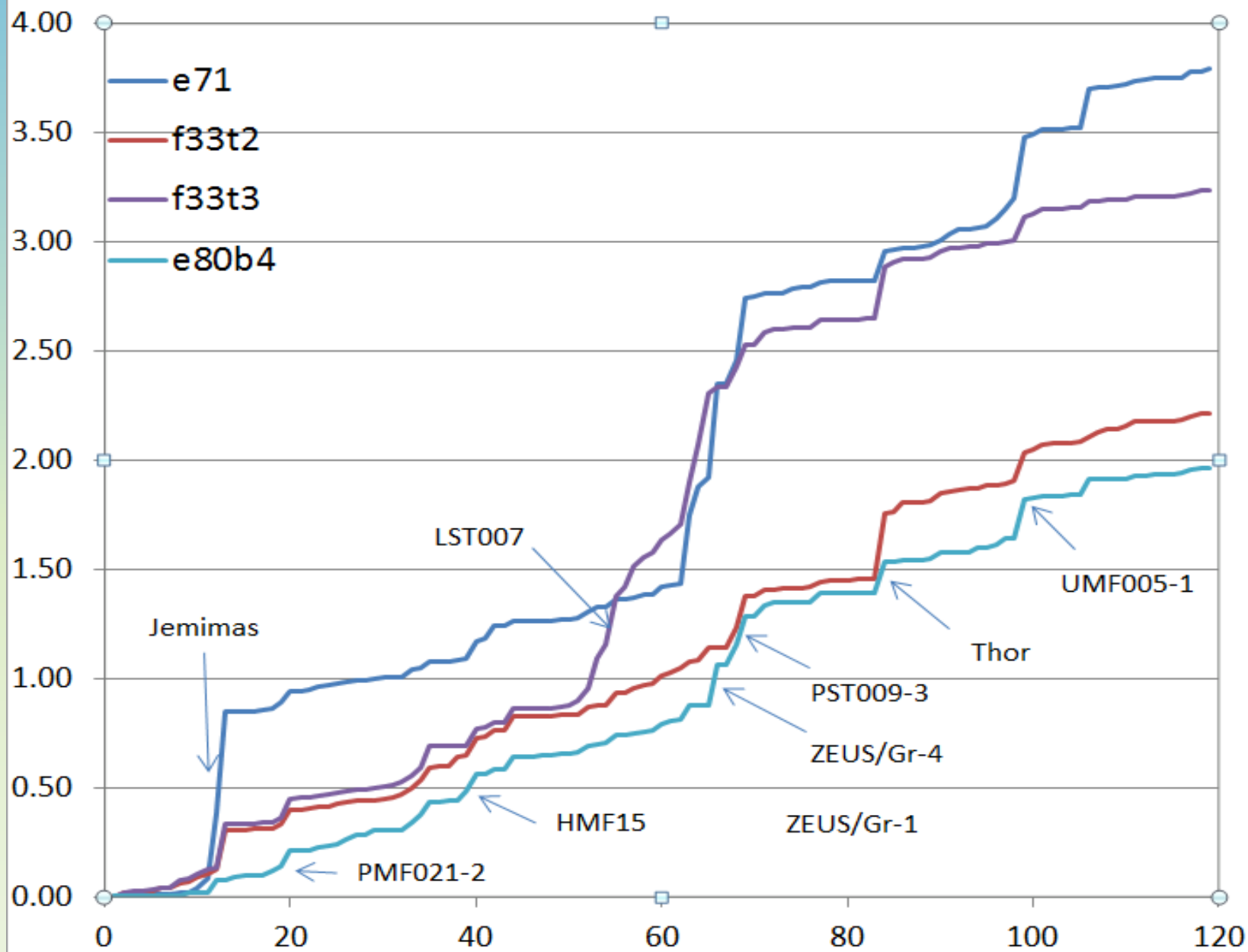
- 119 cases including a variety of assembly types in terms of spectrum, geometry and fissile material composition
- Frequently used by different authors

## Question:

- How to define Figure of Merit (FoM) for comparing performance of different libraries ?

# FoM Options

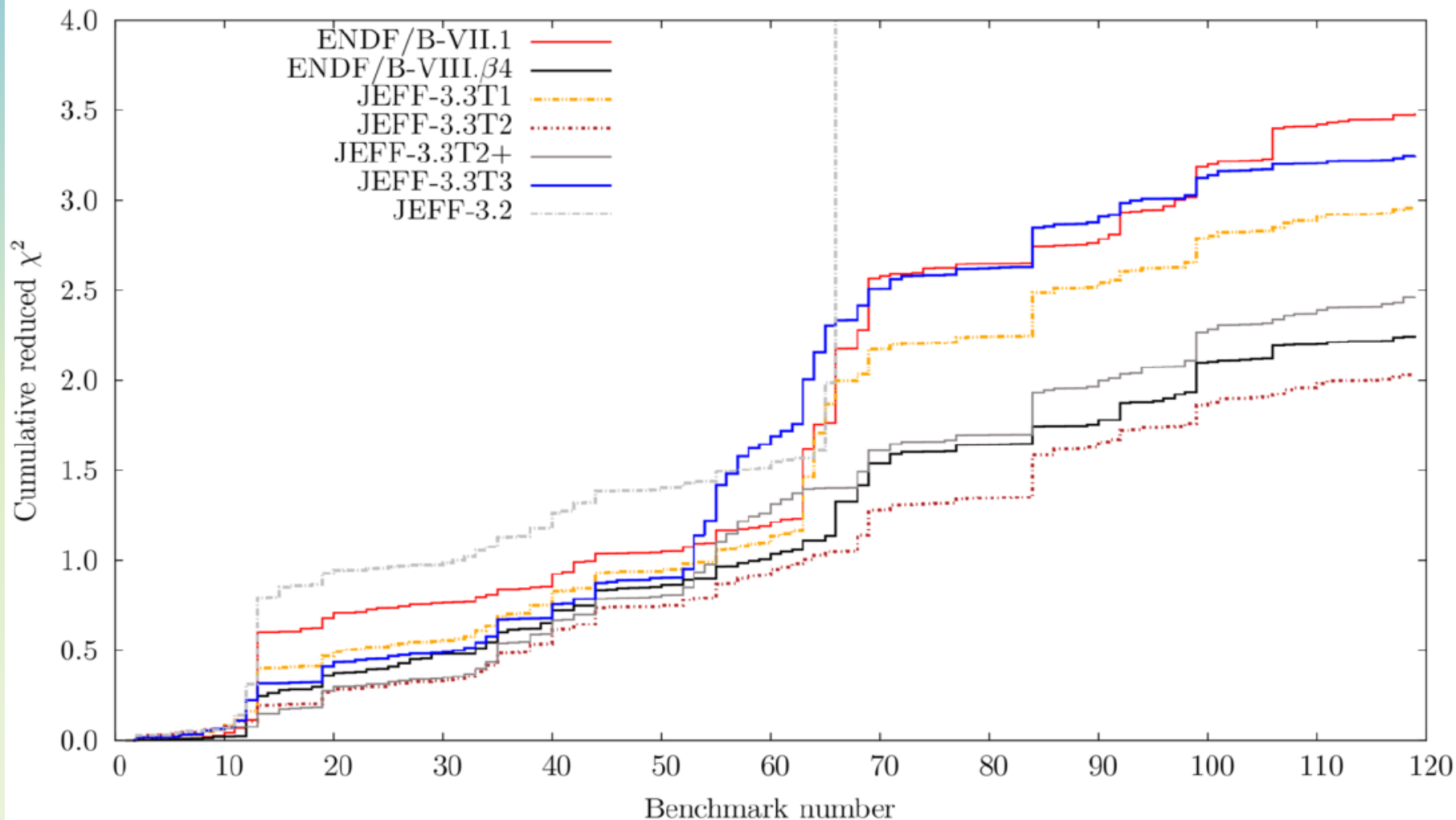
- $\chi^2 = \frac{1}{N} \sum_1^N \left( \frac{k - k_{ref}}{\Delta k_{ref}} \right)^2$  (large weight to small  $\Delta k_{ref}$ )
- $\Delta_{rms}(abs) = \sqrt{\frac{1}{N} (k - k_{ref})^2}$  (all equal weight)
- $\Delta_{rms}(rel) = \sqrt{\frac{1}{N} \left( \frac{k - k_{ref}}{k_{ref}} \right)^2}$  (similar when  $k_{ref} \approx 1$ )



# Comments on FoM

- Subjective
  - A single benchmark with a unreasonably small uncertainty can dominate the  $\chi^2$
  - Rule-of-thumb: recommending  $\Delta_C < \Delta_E/10$  might be difficult to achieve (e.g. Jemima-3,4  $\Delta_E=30$  pcm!!!)
  - $\Delta_{rms(abs)}$  indiscriminantly emphasizes importance of benchmarks with large uncertainties
- Must be interpreted with care !!!
  - Same benchmarks, libraries, codes  $\rightarrow$  different conclusions (e.g. D. Rochman presentation at JEFF)

Benchmark from Mosteller's suite



# Other unresolved issues

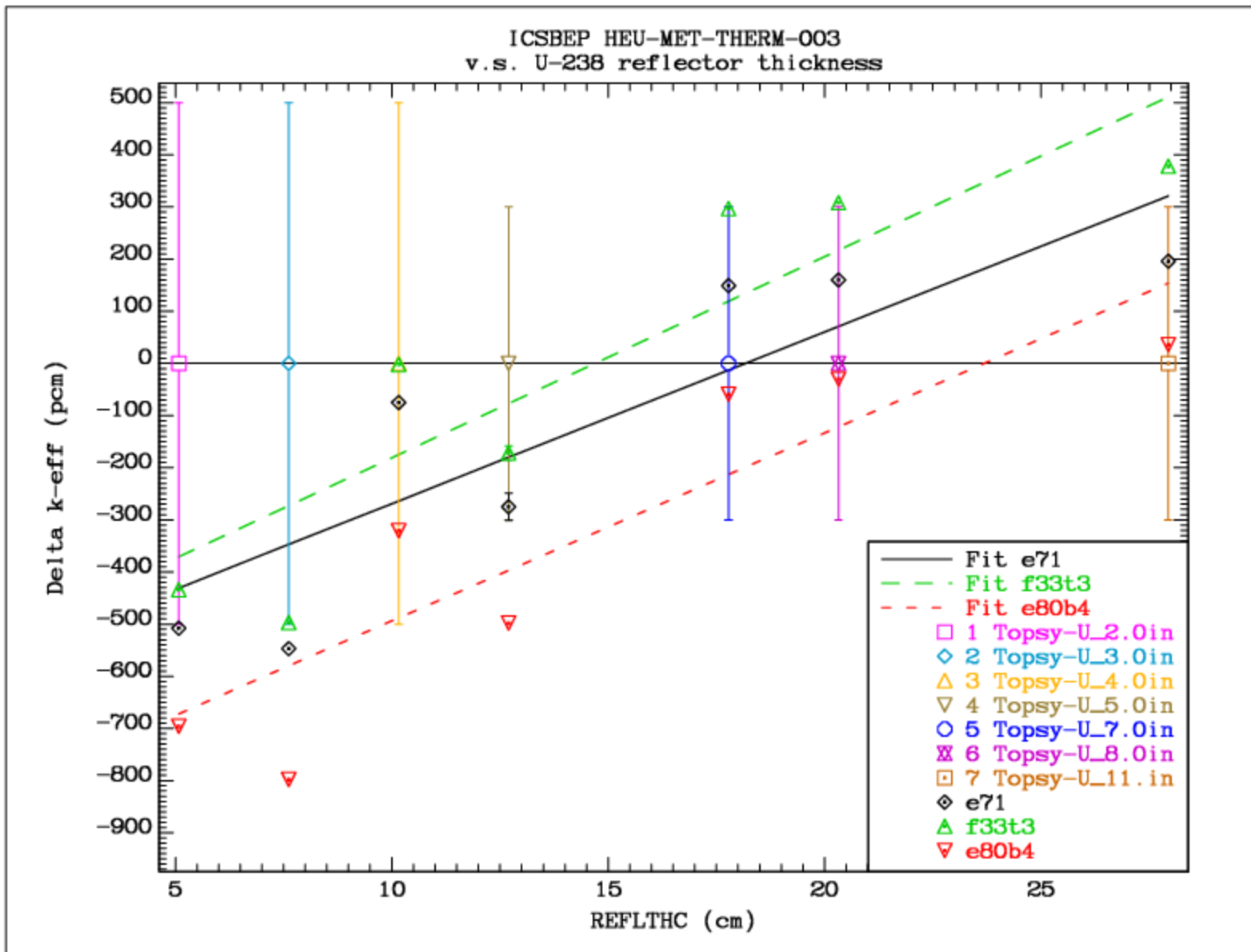
Drift in calculated reactivity with:

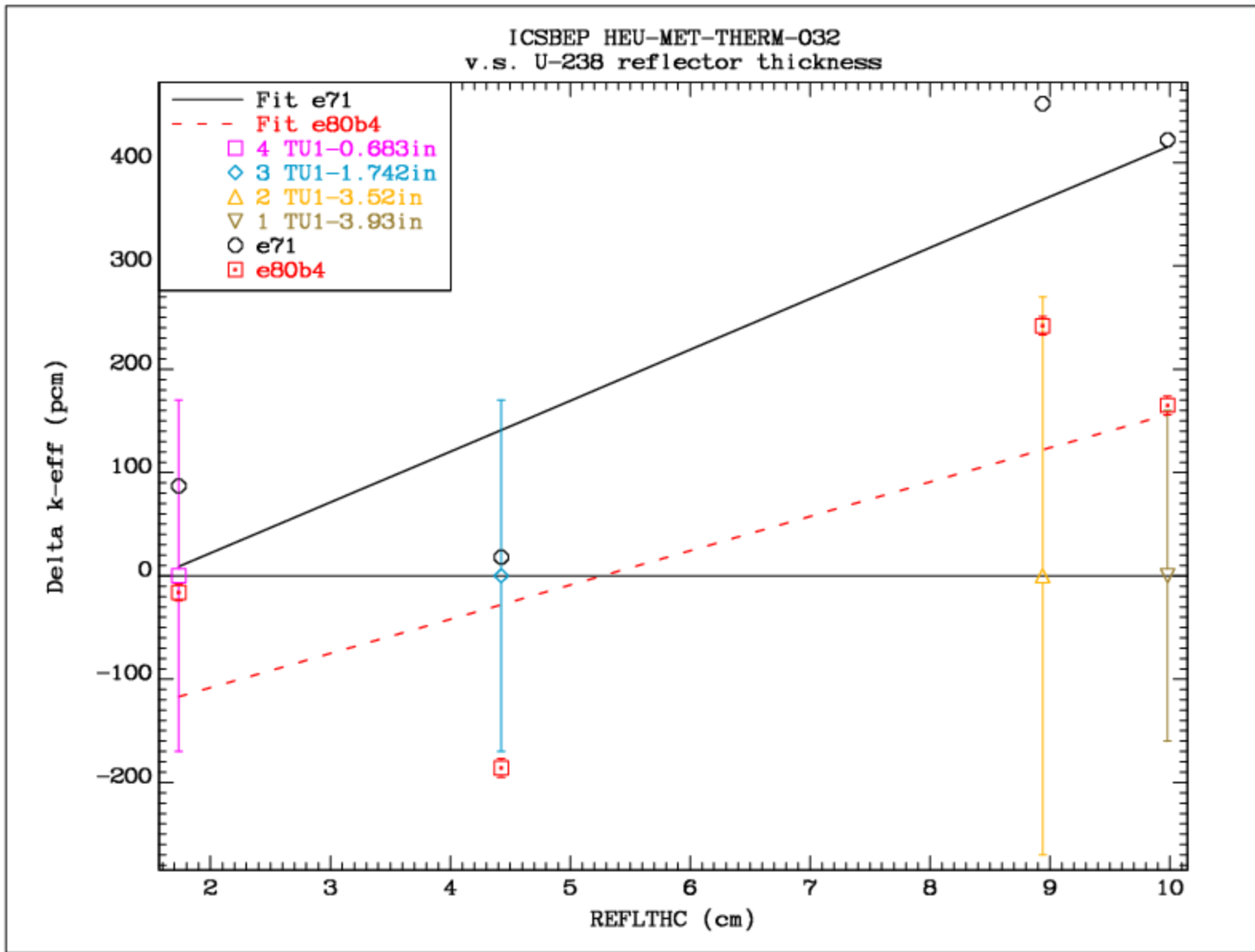
- $^{238}\text{U}$  reflector thickness
- EALF for thermal assemblies with metal-fuel
- $\text{D}_2\text{O}$  moderated assemblies
  - LANL hst004, hst020 and ETA-I,II are low
  - The rest are all Vinca lmt015 (correlated!)
- Low-enriched compound lattices

# $^{238}\text{U}$ reflector thickness

Drift in calculated reactivity  $\sim 30$  pcm/cm

- hmt003, hmt032

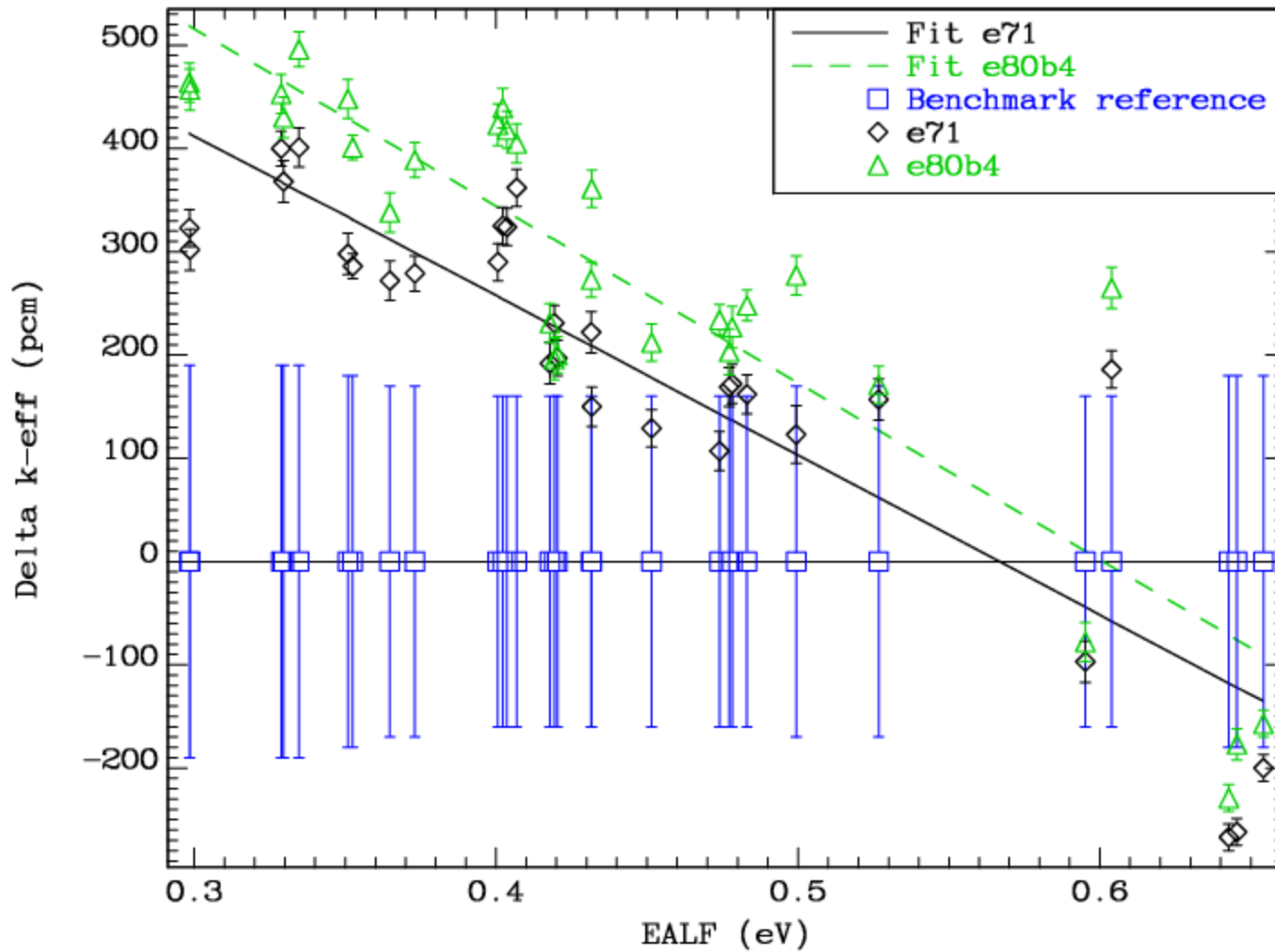




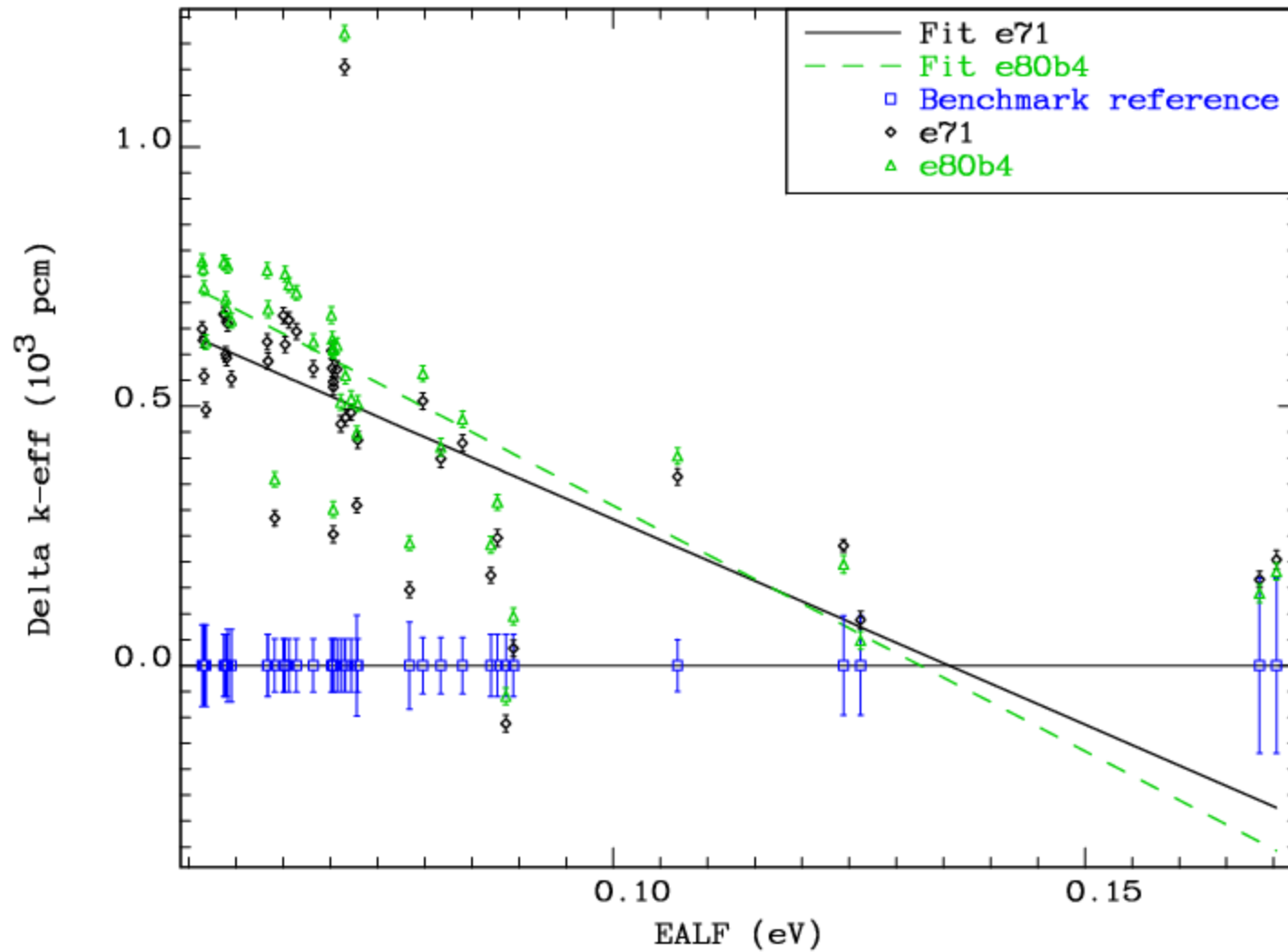
# Thermal assemblies with metal-fuel

- French lmt006 (Bugey) show distinct trend with EALF (inputs: Bor Kos, JSI)
- French hmt011 (Valduc) also show a distinct trend (inputs: Qin Yingcan and WU Haicheng, CNDC)
- ORNL lmt007 has no (or slightly opposite trend), even though the range of EALF is similar to lmt006

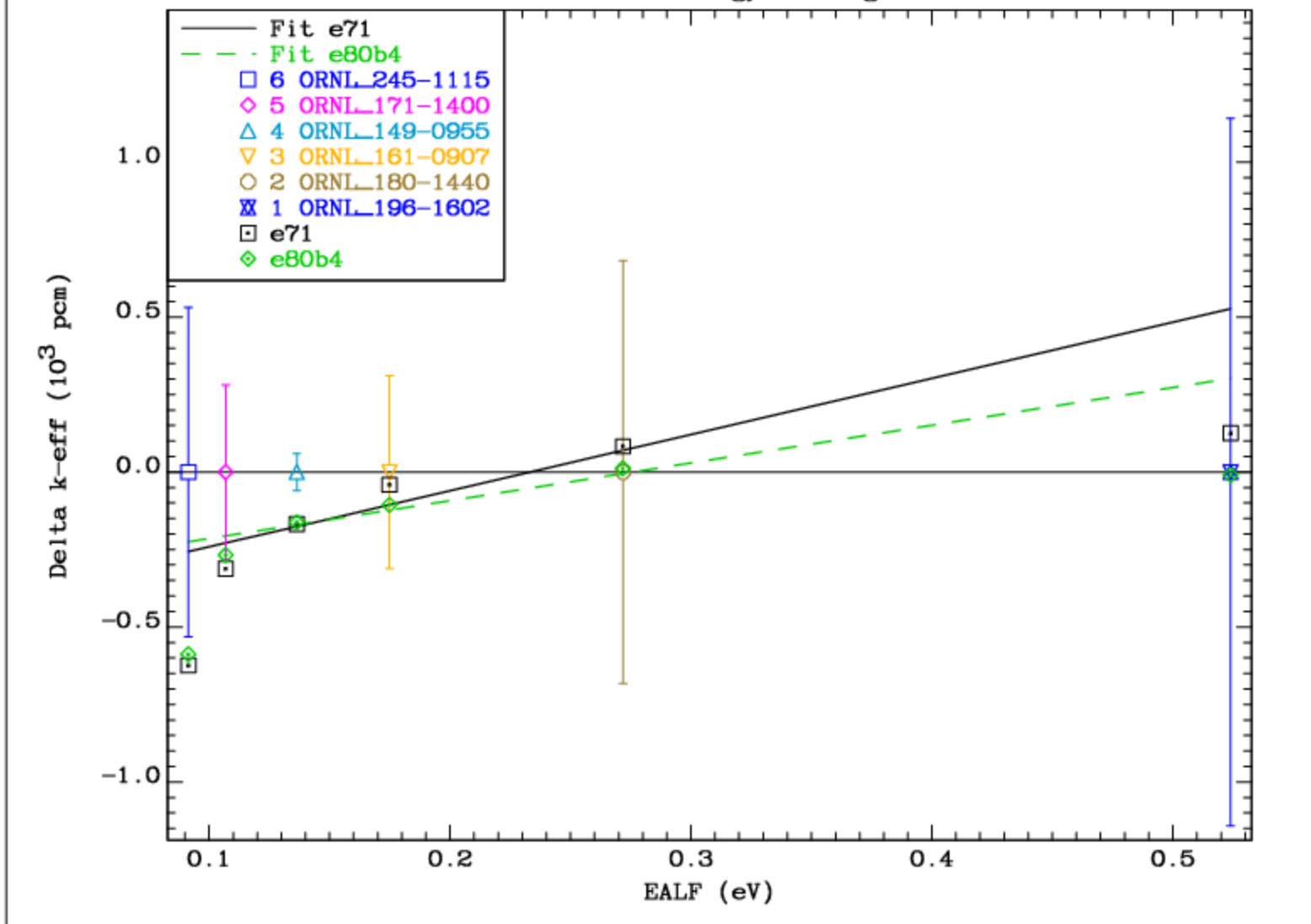
ICSBEF LEU-MET-THERM-006 (Bugey)  
 v.s. E of Aver.Lethargy causing fission



ICSBEP HEU-MET-THERM-011 (Valduc)  
v.s. E of Aver.Lethargy causing fission



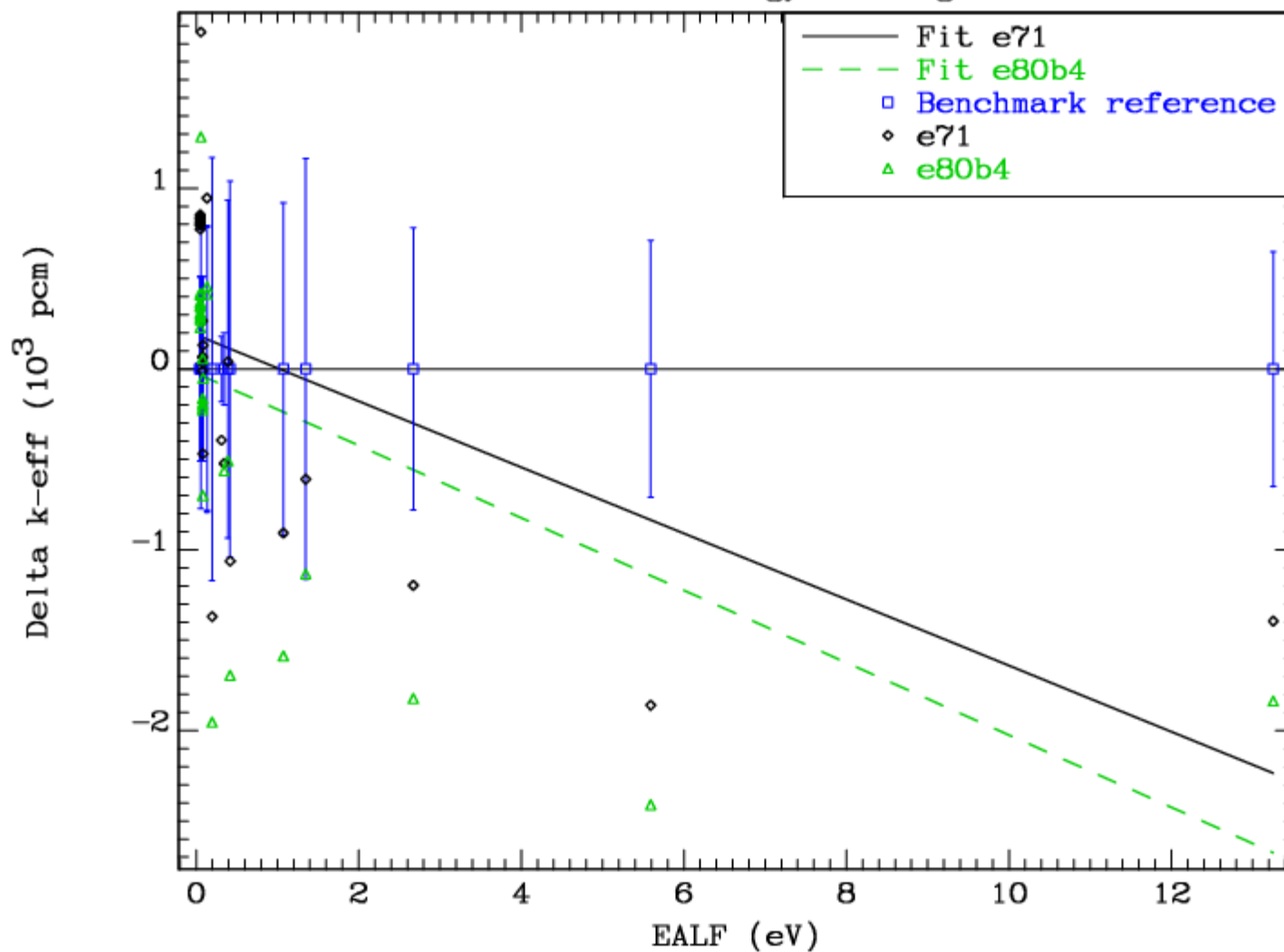
ICSBEP LEU-MET-THERM-007 (ORNL)  
v.s. E of Aver.Lethargy causing fission



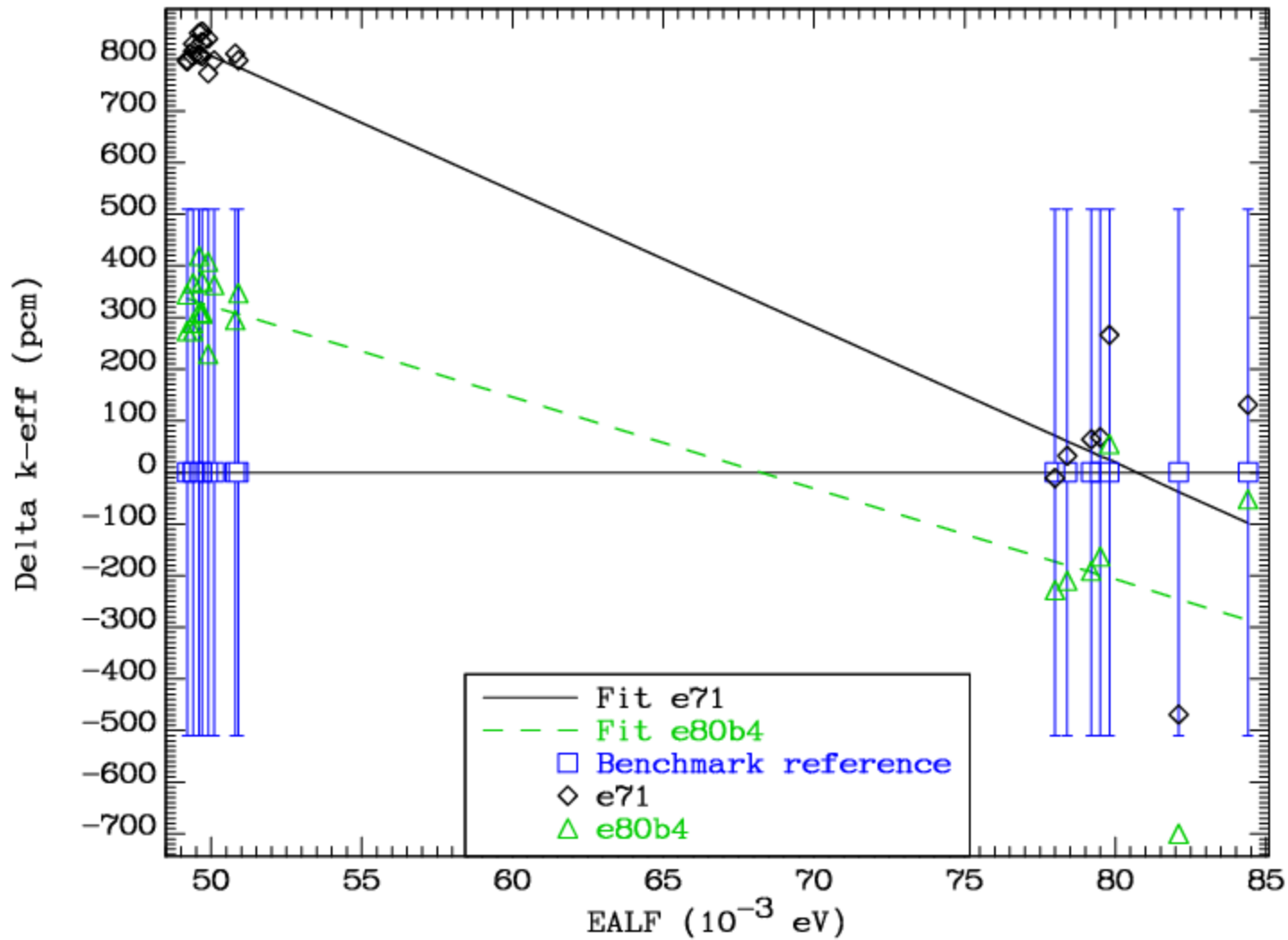
# D2O moderated assemblies

- LANL hst004, hst020 and ETA-I,II are low
  - Discrepancies in calculated reactivity exceed 2% !!!
- The rest are all Vinca lmt015
  - Improved prediction with “e80b4”
  - Benchmarks are correlated

ICSBEP D20 Benchmarks  
v.s. E of Aver.Lethargy causing fission



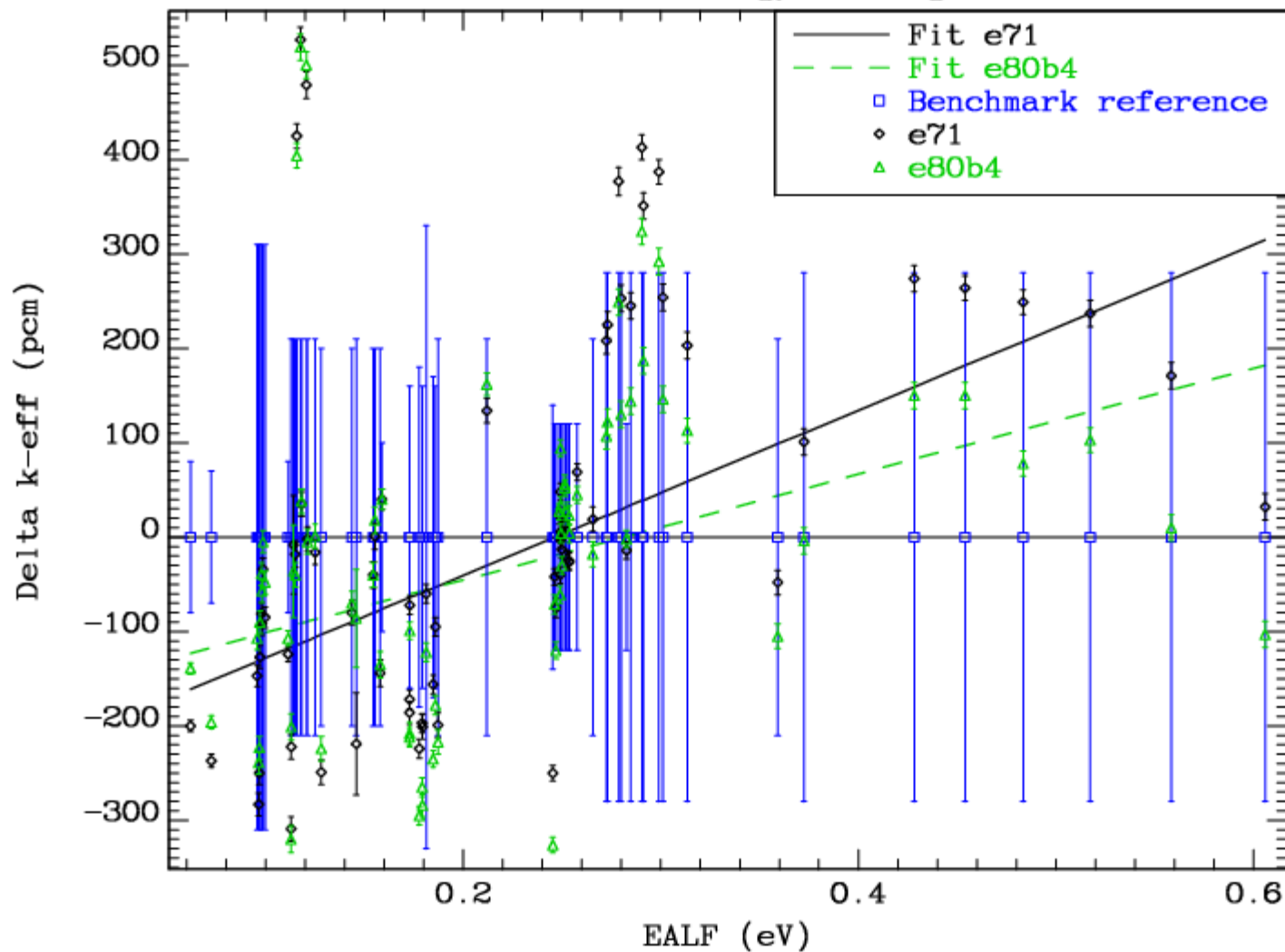
ICSBEP D20 Benchmarks LMT015  
v.s. E of Aver.Lethargy causing fission



# Low-enriched compound “lct”

	ICSBEP name	Common name	Cases
1	LEU-COMP-THERM-001	PNL_2.032	8
2	LEU-COMP-THERM-002	PNL_2.54	5
3	LEU-COMP-THERM-005	PNL_Gd	3
4	LEU-COMP-THERM-007	Valduc	4
5	LEU-COMP-THERM-008	BW-XI	15
6	LEU-COMP-THERM-010	PNL	26
7	LEU-COMP-THERM-009		2
8	LEU-COMP-THERM-042		7
9	LEU-COMP-THERM-043		1

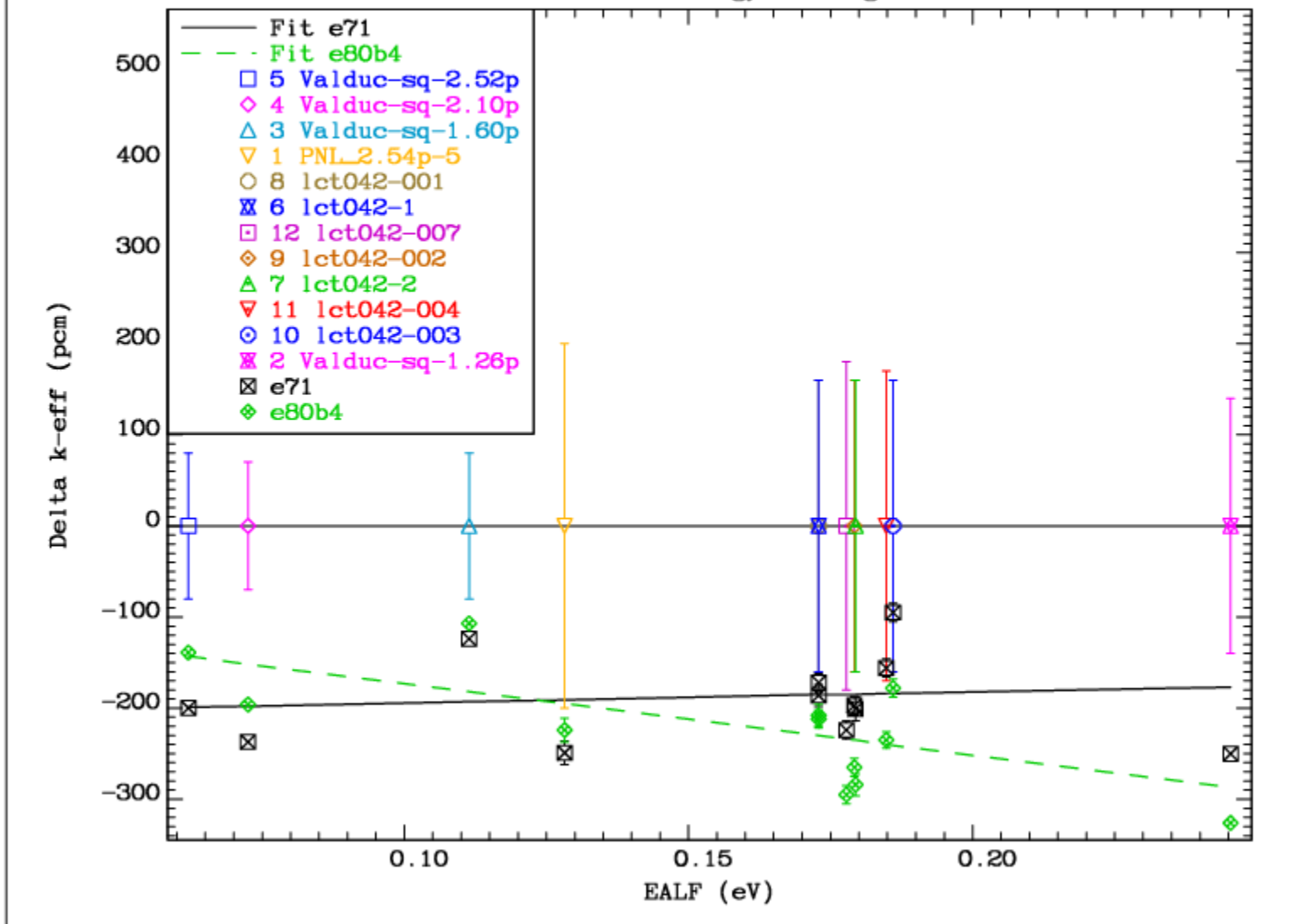
ICSBEP LEU-COMP-THERM Benchmarks  
v.s. E of Aver.Lethargy causing fission



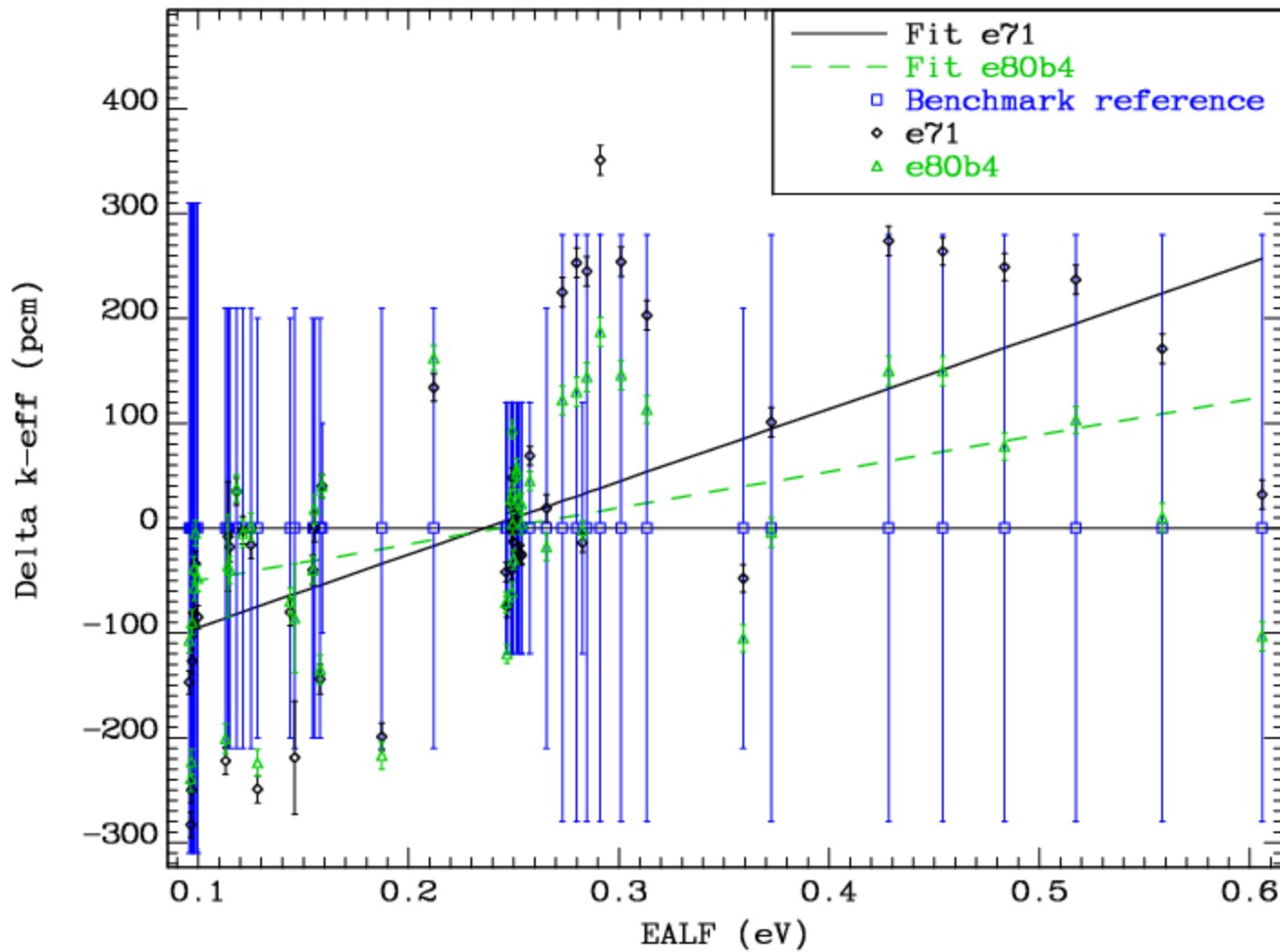
# Comment

- Big (positive) outliers are lct010 with Pb
- Excluding lct010 with Pb and plotting only one-sigma outliers with e80b4, it turns out that they all underestimate reactivity and belong to:
  - Valduc (lct007)
  - lct042
- The remainder still exhibit a slight gradient (less with e80b4), but within uncertainty.
  - No correlations between benchmarks are accounted for!

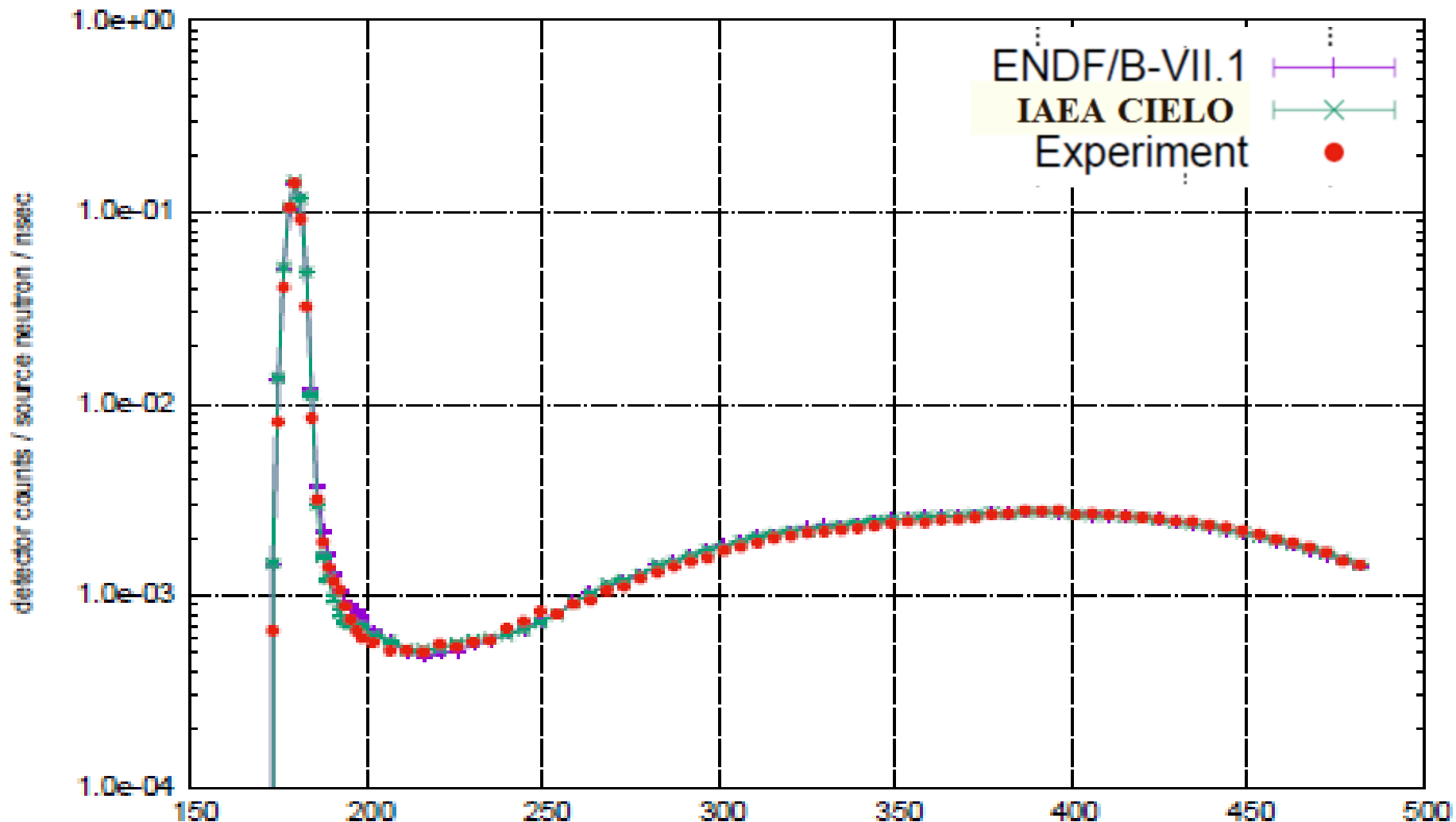
ICSBEF LEU-COMP-THERM Benchmarks  
v.s. E of Aver.Lethargy causing fission



ICSBEF LEU-COMP-THERM Benchmarks  
v.s. E of Aver.Lethargy causing fission

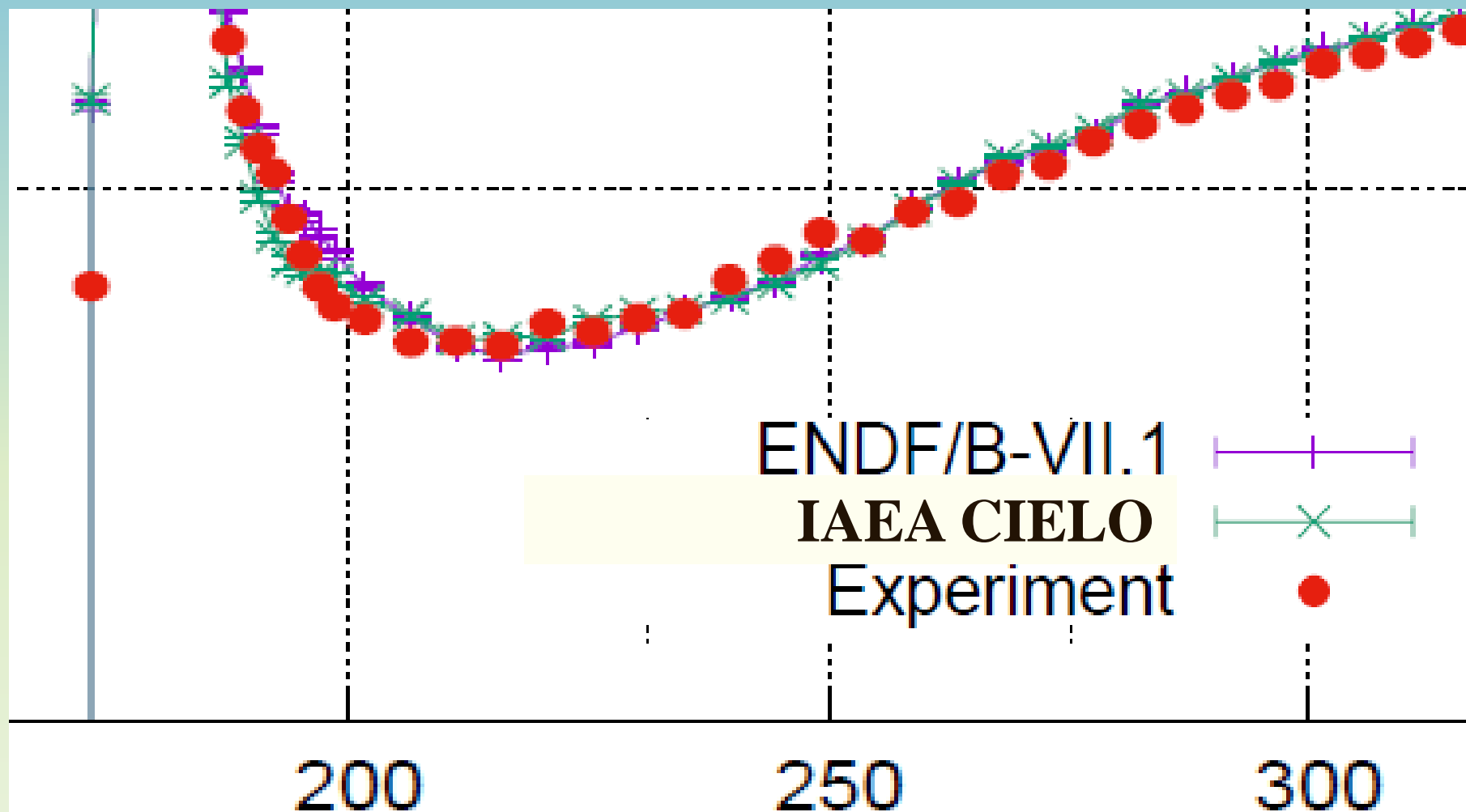


# LLNL Pulsed Sphere (14MeV n + $^{235}\text{U}$ )

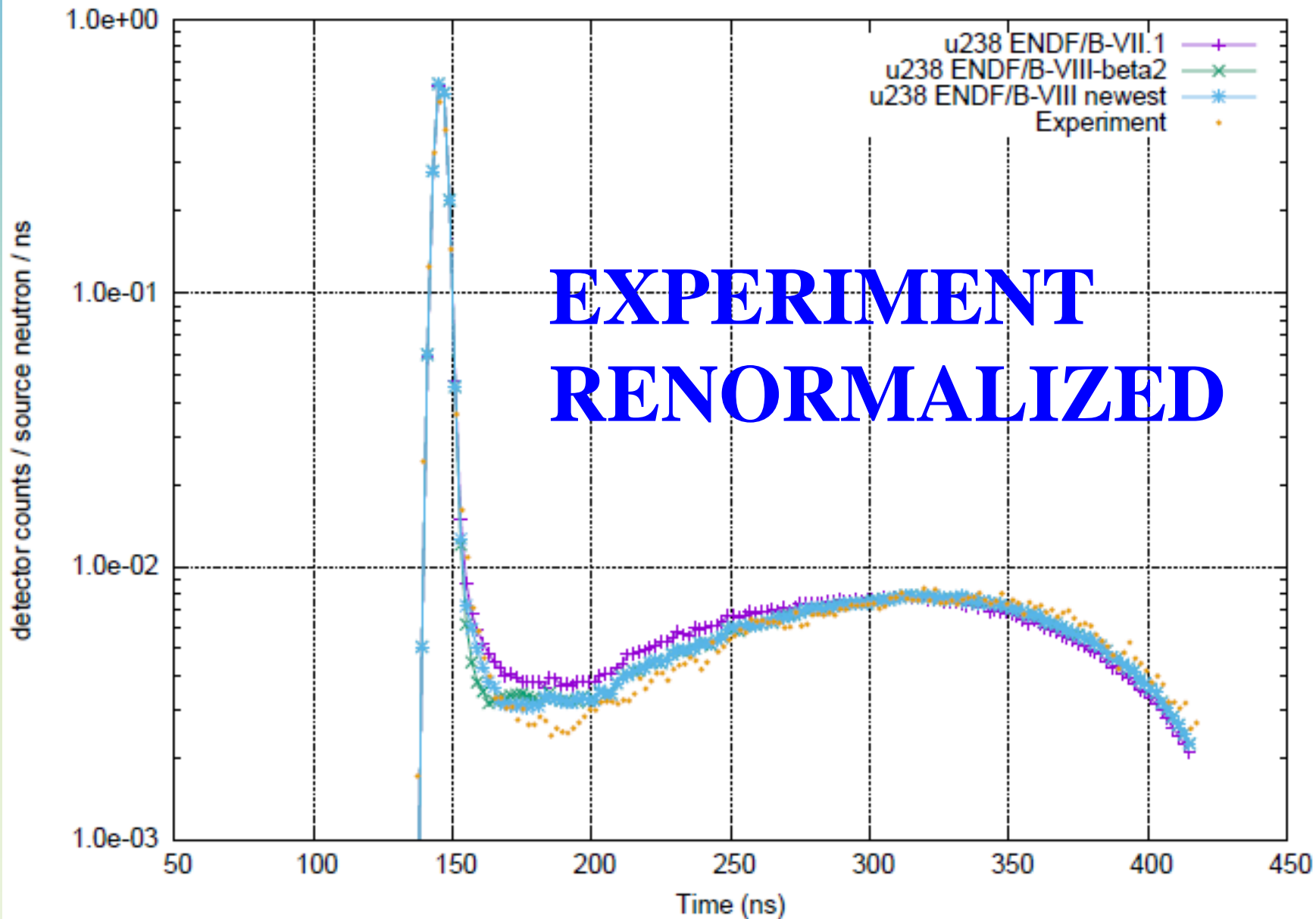


LLNL Pulsed Spheres calculations by B. Kiedrowski using MCNP

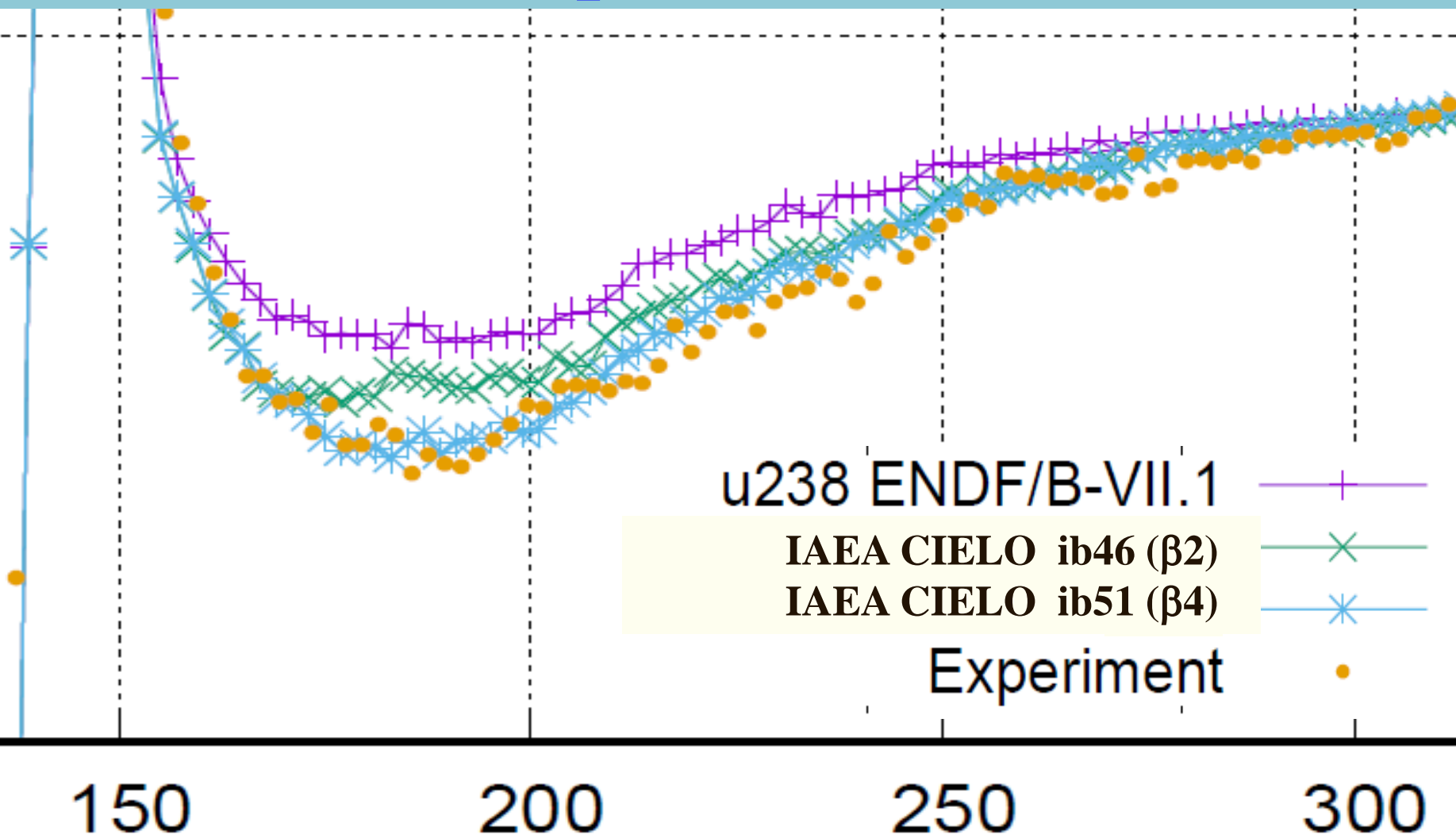
# LLNL Pulsed Sphere (14MeV n + $^{235}\text{U}$ )



LLNL Pulsed Spheres calculations by B. Kiedrowski using MCNP



# LLNL Pulsed Sphere (14MeV n + $^{238}\text{U}$ )



LLNL Pulsed Sphere calculations by B. Kiedrowski using MCNP

# Conclusions

- Check integral benchmarks
  - Inconsistent benchmark specifications (e.g. hmf080)
  - Unreasonable small uncertainties (or none, e.g.: hmf004)
  - Contradictory trends (e.g.: lmt006, hmt011 v.s. lmt007)
- Use FoM with caution
  - small uncertainties
- Independent cross-checking of results
  - Input modes – same transport code
  - Different transport codes

# Thanks !

