	COMP				MET			
	therm	inter	fast	mixed	therm	inter	fast	mixed
LEU	462				31			
IEU	36	4	1				21	
HEU	156	6	6	8	52	5	284	6
MIX	100		9				33	
PU		1		34		5	100	6
^{233}U	8				1		10	
Total	762	11	16	42	84	10	448	12

TABLE III. The number of benchmarks per main ICSBEP category for compound and metal systems with thermal, intermediate, fast and mixed neutron spectra.

	SOL				MISC			
	therm	inter	fast	mixed	therm	inter	fast	mixed
LEU	67							
IEU	60							
HEU	402							
MIX	53				60		10	
PU	385							
^{233}U	60	33						
Total	1027	33			60		10	

TABLE IV. The number of benchmarks per main ICSBEP category for solution and miscellaneous systems with thermal, intermediate, fast and mixed neutron spectra.

2, 4, 6 of ieu-comp-therm-002 and for all cases of heu-sol-therm-039 the nuclear data were processed for the temperatures specified by the benchmark.

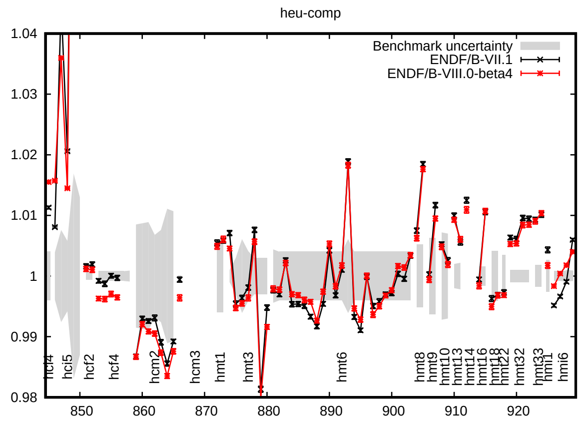

FIG. 17. C/E values for criticality safety benchmark cases (1)

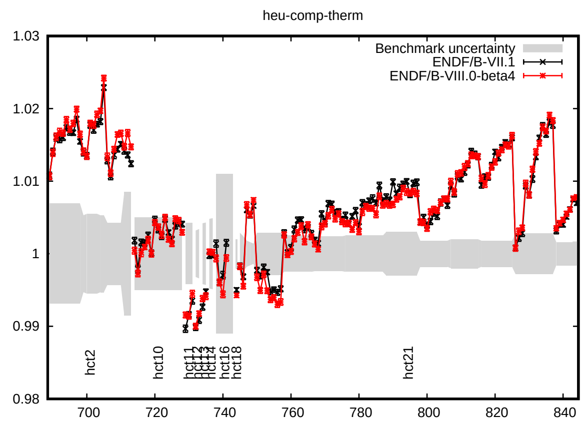

FIG. 18. C/E values for criticality safety benchmark cases (2)

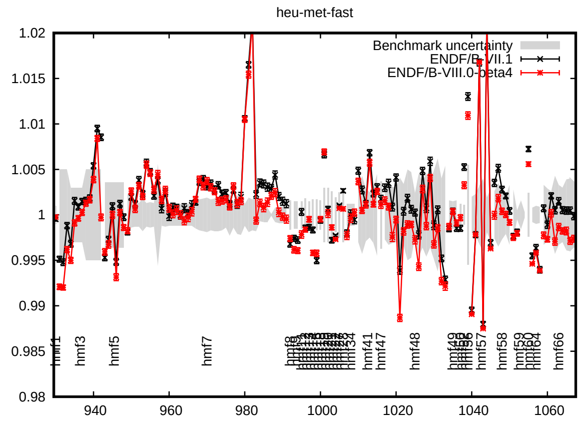

FIG. 19. C/E values for criticality safety benchmark cases (3)

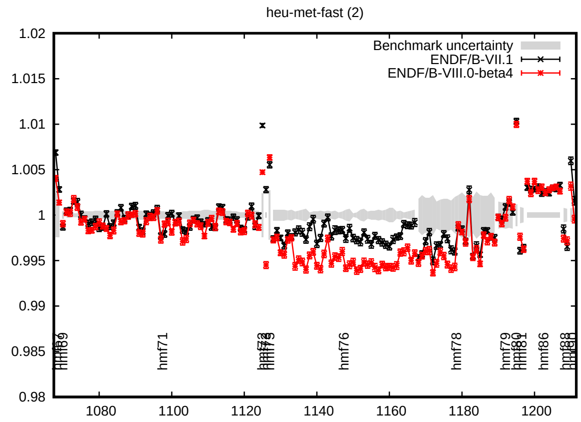

FIG. 20. C/E values for criticality safety benchmark cases (4)

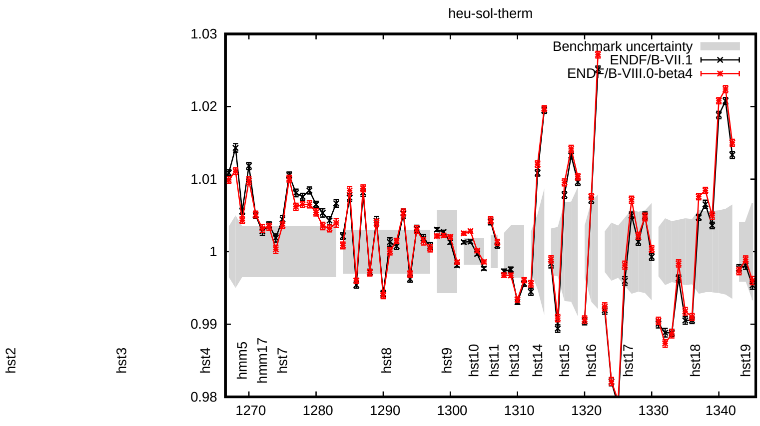

FIG. 21. C/E values for criticality safety benchmark cases (5)

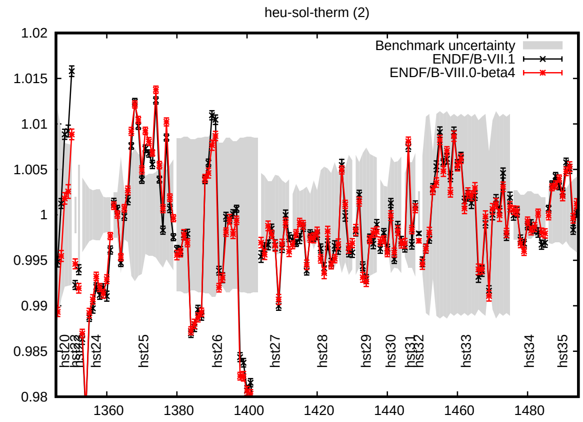

FIG. 22. C/E values for criticality safety benchmark cases (6)

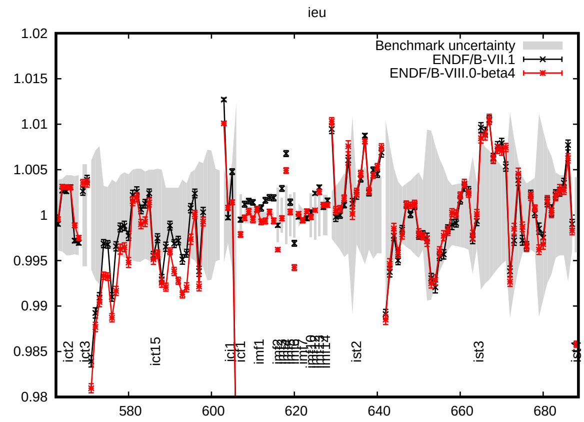

FIG. 23. C/E values for criticality safety benchmark cases (7)

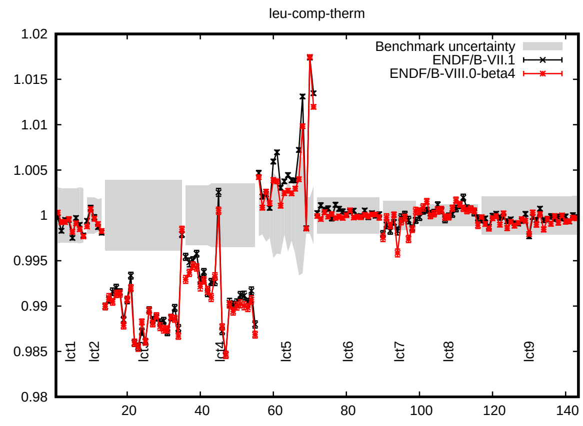

FIG. 24. C/E values for criticality safety benchmark cases (8)

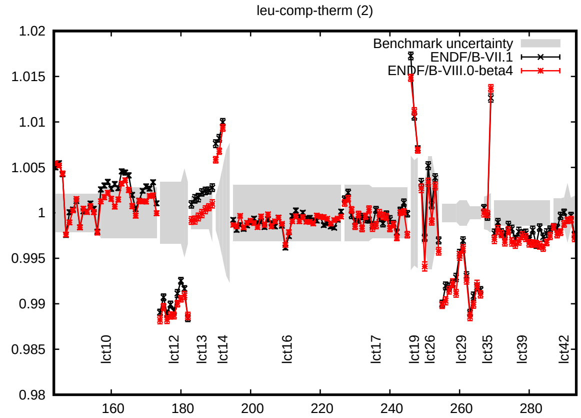

FIG. 25. C/E values for criticality safety benchmark cases (9)

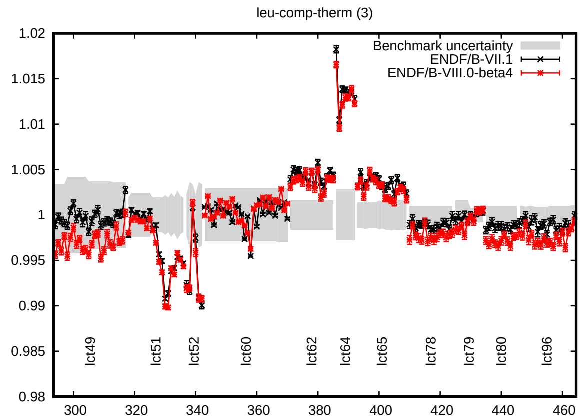

FIG. 26. C/E values for criticality safety benchmark cases (10)

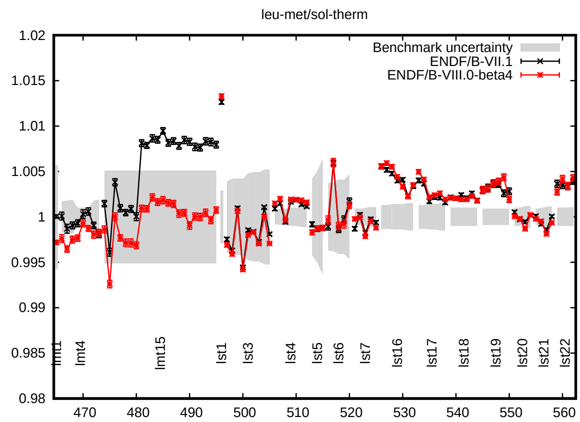

FIG. 27. C/E values for criticality safety benchmark cases (11)

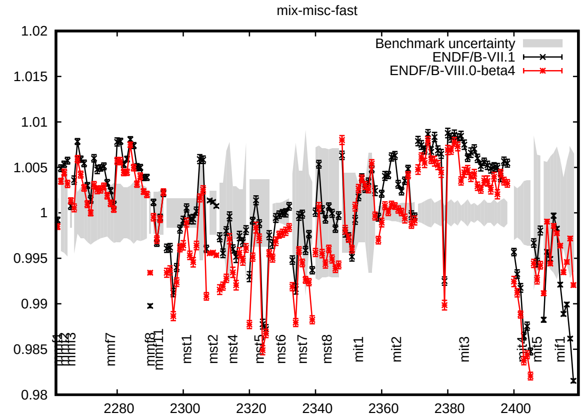

FIG. 28. C/E values for criticality safety benchmark cases (12)

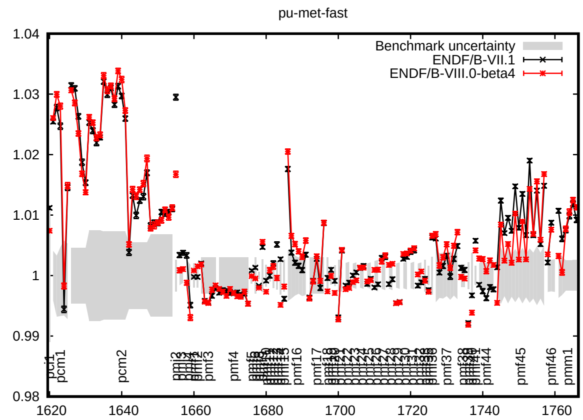

FIG. 29. C/E values for criticality safety benchmark cases (13)

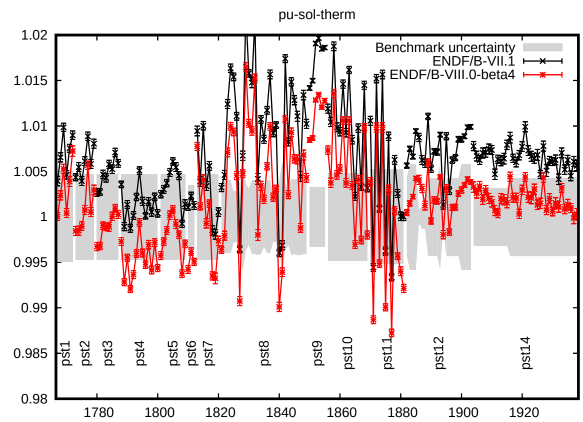

FIG. 30. C/E values for criticality safety benchmark cases (14)

The criticality safety calculations were performed with MCNP-6.1.1. The average results for all these calculations are summarized in Tables V–VI, for each main category of the International Criticality Safety Benchmark Evaluation Project (ICSBEP). In these tables the results based on ENDF/B-VII.1 are also listed (sed on

	COMP therm	COMP inter	COMP fast	COMP mixed	MET therm	MET inter	MET fast	MET mixed
LEU	-144 ± 473				-91 ± 204			
	−77 ± 477				*395 ± 432*			
IEU	-391 ± 511	-367 ± 1396	-213				-5 ± 200	
	−219 ± 435	*−253 ± 1506*	*−50*				*120 ± 187*	
HEU	764 ± 1242	2693 ± 4355	-196 ± 219	-1063 ± 369	123 ± 694	126 ± 186	-85 ± 412	188 ± 573
	788 ± 1276	*2112 ± 5062*	*20 ± 118*	*−892 ± 413*	*143 ± 725*	*23 ± 424*	*31 ± 387*	*640 ± 696*
MIX	-346 ± 1080		-349 ± 198				229 ± 275	
	−141 ± 1148		*−39 ± 220*				*364 ± 363*	
PU		742		1979 ± 952		211 ± 787	158 ± 492	763 ± 438
		1119		*1910 ± 955*		*702 ± 1170*	*162 ± 516*	*921 ± 194*
^{233}U	-220 ± 144				-2806		-110 ± 133	
	23 ± 134				*−3466*		*−220 ± 162*	

TABLE V. The average value of $C/E-1$ in pcm (100 pcm=0.1%) for ENDF/B-VIII.0 per main ICSBEP category for compound and metal systems. Shown in *italics* are the values for the ENDF/B-VII.1 library.

	SOL therm	SOL inter	SOL fast	SOL mixed	MISC therm	MISC inter	MISC fast	MISC mixed
LEU	133 ± 293							
	133 ± 270							
IEU	90 ± 505							
	53 ± 583							
HEU	22 ± 925							
	64 ± 914							
MIX	-545 ± 352				65 ± 599		-453 ± 260	
	−194 ± 365				*254 ± 576*		*−845 ± 539*	
PU	61 ± 535							
	454 ± 587							
^{233}U	285 ± 721	-1794 ± 833						
	540 ± 732	*−1544 ± 823*						

TABLE VI. The average value of $C/E-1$ in pcm (100 pcm=0.1%) for ENDF/B-VIII.0 per main ICSBEP category for solution and miscellaneous systems. Shown in *italics* are the values for the ENDF/B-VII.1 library.

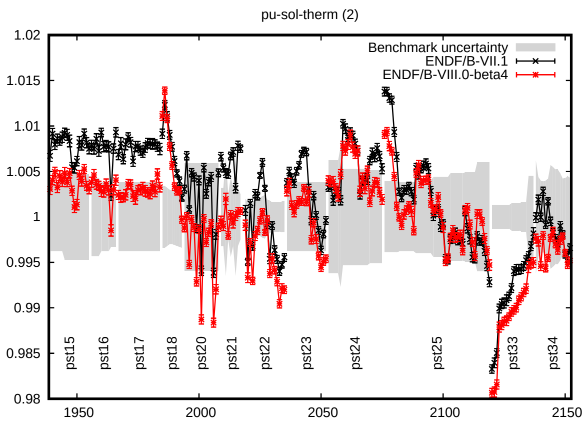

FIG. 31. C/E values for criticality safety benchmark cases (15)

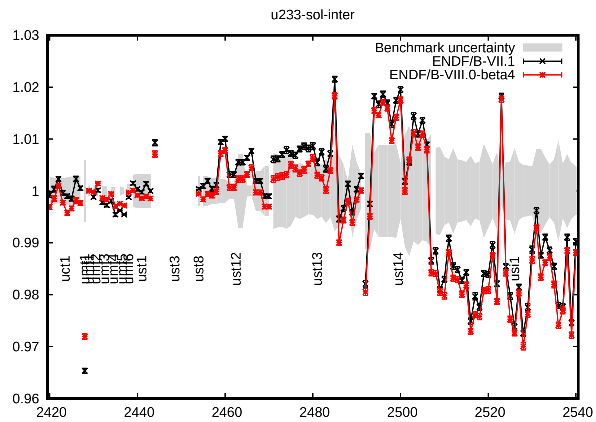

FIG. 32. C/E values for criticality safety benchmark cases (16)

exactly the same benchmark cases), for easy comparison. In all 2515 benchmark cases were calculated with both ENDF/B-VII.0 and ENDF/B-VII.1. The values for ENDF/B-VII.1 differ from those in Ref. [2], because many benchmark cases have been added since.

The values in the tables are averages and standard deviations around the averages, and it is therefore hard to interpret the differences between the libraries. In combination with the Figures **??**–**??**, several observations that can be made.

- Results for most of the compound cases with a thermal spectrum have decreased slightly, while the spread in the results is roughly the same. E.g. for the leu cases, the average $C/E - 1$ has decreased from -77 to -144, while the standard deviation around it is virtually unchanged.
- The average for the leu-met-therm cases has improved, which is mainly due to the results for leu-met-therm-015 (2% enriched uranium in heavy water). The cases with 16 cm pitch are now within the experimental uncertainty band, which the 8 cm cases already were.
- The average for the heu-met-inter cases has improved because of a better performance for the varying C/^{235}U ratio in heu-met-inter-006 (Zeus, a graphite-heu core surrounded by a copper reflector).
- The average for pu-met-inter cases is much better due to the improved description of pu-met-inter-002 (ZPR-6, Assembly 10, a plutonium-carbin-stainless steel core with stainless steel and iron reflector), a benchmark for which all calculations so far were far too high (in fact, the calculated value for pu-met-inter-002 is still more than 1500 pcm high).
- The averages and standard deviations for heu-met-fast and pu-met-fast cases have changed only slightly.
- The average for mix-met-fast cases has come down by 135 pcm, while at the same time the standard deviation around this average has decreased significantly. This is because the results for mix-met-fast-002 and -007, which are spherical cores with uranium and beryllium reflectors, are lower, while the result for mix-met-fast-008, which is a k-infinity benchmark, is higher.
- The average and standard deviation for u233-met-fast cases have both improved somewhat, as a result of higher results for the u233-met-fast-002, 003, 004, and 005 benchmarks, all of which are spherical cores (with different reflectors).
- The average for pu-met-mixed cases has gone down by 158 pcm, which is an improvement. This is due to better results for cases 1 and 2 of pu-met-mixed, while cases 3–6 have stayed the same, leading to an increase of the standard deviation.
- Most of the pu-sol-therm and u233-sol-therm cases have lower results than before, which is an improvement. The spread in the results is roughly unchanged, however.
- The mix-sol-therm cases also have lower results than before, which in this case is not an improvement.

The results of all criicality benchmark calculations can also be summarized as in Figure 33. All the benchmark cases with e.g. a thermal spectrum are lumped together, and a normal distribution is fitted to the distribution of C/E values (expressed in units of a standard deviation). In case of 'perfect' nuclear data (and 'perfect' benchmark evaluations), the distribution of C/E would be the normal distribution with average zero (0) and standard deviation one (1). The Figure shows that for thermal and fast spectrum cases, the distribution based on ENDF/B-VIII.0 is slightly more peaked than the one based on ENDF/VII.1, which is an improvement. For the intermediate and mixed spectrum cases, the statistics are too low for firm conclusions, but for these cases there appears to be a bias in the $k_{\rm eff}$ calculations that is roughly identical for ENDF/B/VIII.0 and ENDF/B-VII.1: for most of the intermediate spectrum cases the calculated value lies more than one standard deviation *below* the benchmark value, whereas for mixed spectrum cases most of the calculated value lie more than one standard deviation *above* the benchmark value.

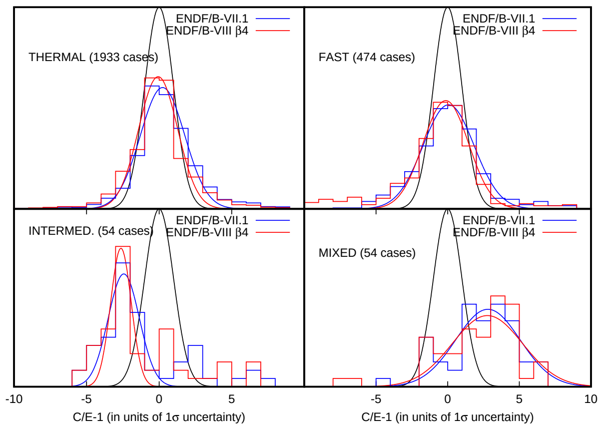

FIG. 33. The distribution of C/E, in units of the combined benchmark and statistical uncertainty. The normal distribution (in black) would be the perfect situation.

B. Delayed Neutron Testing

Although the delayed neutron data have not been changed with respect to ENDF/B-VII.1, these data have been tested against measurements of effective delayed neutron fraction $\beta_{\rm eff}$ in critical configurations. Unlike the situation for $k_{\rm eff}$, only a handful of measurements of $\beta_{\rm eff}$ have been reported in open literature with sufficiently detailed information. In Ref. [28] more than twenty measurements are listed, including several measurements of Rossi-α, which is closely related to $\beta_{\rm eff}$ through the prompt neutron generation life time. We avoid the term 'benchmark' for these cases, because a good benchmark description, comparable to those given in the ICSBEP Handbook [30], is not available.

These measurement data were used for testing ENDF/B-VII.0 in 2006 [1, 28] and ENDF/B-VII.1 in 2011 [2]. These comparisons were made on the basis of non-standard version of MCNP, including an approximate method to calculate $\beta_{\rm eff}$. Since then version 6 of MCNP was released, in which an improved method for adjoint weighting has been implemented. This standard version of MCNP produces results for both $\beta_{\rm eff}$ and Rossi-α, enabling an even better comparison between measurements and calculations. An alpha release of MCNP6 was used 2012 in combination with ENDF/B-VII.1 to test the delayed neutron data in Ref. [29]. The current release of the library has been tested using a standard MCNP6 release, in this case 6.1.1.

The measurement data include several cores with thermal spectrum, all of which are fueled by ^{235}U. In most of these cases the uranium is low enriched (Sheba-II, SHE-core8, Stacy cores, TCA cores and the IPEN/MB01 core), with only one core with high enriched uranium (Winco slab tank). As a consequence, for thermal spectrum data only the ^{235}U delayed neutron data are tested by these calculations.

For many of the fast spectrum cores, not only ^{235}U was used as fuel (Masurca, FCA, SNEAK, ZPR, Godiva), but also plutonium (FCA, ZPR, Jezebel) and a mix of the two (Masurca, FCA, SNEAK, ZPR). Also there are cores with ^{233}U (Skidoo). Using these fast spectrum cases, the ^{233,235,238}U and ^{239}Pu data are tested. Also, one should bear in mind that the tests performed here are only sensitive to the total delayed neutron yields. The delayed neutron yields per group are not tested, nor are the values for the decay constant per group.

The results based on ENDF/B-VIII.0 are given in Tables VII and VIII, as well as the results based on other libraries. As expected, the results are similar to those obtained with ENDF/VII.1. The result for Sheba-II based on ENDF/B-VII.1 is slightly different from the one in Ref. [29], because that was based on the beta4 release of the library, which contained a version of the ^{19}F data that influenced this calculation. Also, compared with Ref. [2, 29], the results for the Proteus have been omitted, because of concerns about the representativity of the model that was used.

C. Calculated Critical Masses

D. AMS at 25 keV and 426 keV

E. Maxwellian-Avereaged Cross Sections (MACS)

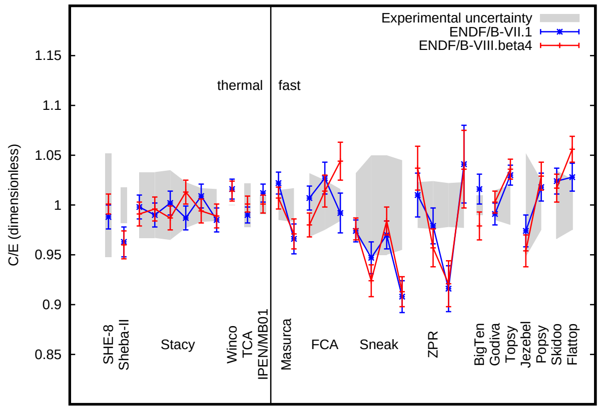

FIG. 34. The values for $C/E-1$ for the delayed neutron tests. The systems are roughly ordered according to the average energy at which fission takes place, from low energy (left) to high (right).

TABLE XI: Maxwellian-averaged cross sections from ENDF/B-VII.0, ENDF/B-VII.1, ENDF/B-VIIIβ_3, ENDF/B-VIIIβ_4 and KADoNiS at kT=30 keV. T-theoretical data in KADoNiS.

Material	**VII.0** (barns)	**VII.1** (barns)	**VIIIβ_3** (barns)	**VIIIβ_4** (barns)	**KADoNiS** (barns)
1-H - 1	1.559E-4	1.559E-4±5.890E-6	1.559E-4±5.830E-6	1.544E-4±5.842E-6	2.540E-4±2.000E-5
1-H - 2	1.980E-6	1.980E-6±1.236E-7	1.980E-6±1.236E-7	1.980E-6±1.236E-7	3.000E-6±2.000E-7
1-H - 3					
2-He- 3	2.483E-8	2.109E-5	2.109E-5	2.109E-5	7.600E-6±6.000E-7
2-He- 4					
3-Li- 6	3.290E-5	3.290E-5±3.180E-6	3.290E-5±3.180E-6	3.290E-5	
3-Li- 7	4.663E-5	4.663E-5	4.663E-5	4.663E-5	4.200E-5±3.000E-6
4-Be- 7					
4-Be- 9		9.324E-6±1.860E-6	9.324E-6±1.860E-6	9.324E-6±1.860E-6	1.040E-5±1.600E-6
5-B - 10	4.311E-4	4.311E-4±3.449E-4	4.311E-4±3.449E-4	3.440E-4	
5-B - 11		6.620E-5±2.047E-5	6.620E-5±2.047E-5	6.620E-5±2.047E-5	
6-C - 0	1.350E-6	1.618E-5±3.234E-6	1.618E-5±3.234E-6	1.618E-5±3.234E-6	
6-C - 12			1.557E-5	1.557E-5	1.540E-5±1.000E-6
6-C - 13			1.736E-5	1.736E-5	2.100E-5±1.000E-6
7-N - 14	6.696E-5	6.696E-5	6.696E-5	6.696E-5	4.100E-5±6.000E-5^C
7-N - 15	9.175E-6	9.175E-6±4.587E-6	9.175E-6±4.587E-6	9.175E-6±4.587E-6	5.800E-6±6.000E-7
8-O - 16	1.696E-7	3.149E-5±3.158E-6	3.151E-5	3.637E-5	3.800E-5±4.000E-6
8-O - 17	4.694E-6	4.695E-6	4.695E-6	4.695E-6	