Trial Evaluation and Validation of the U-235 Data in Thermal and keV Energy Region

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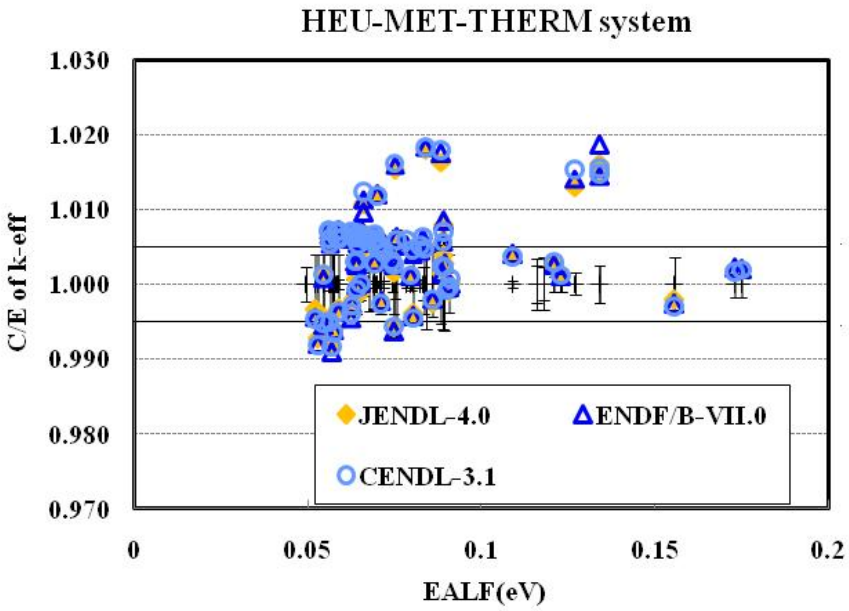
OUTLINE

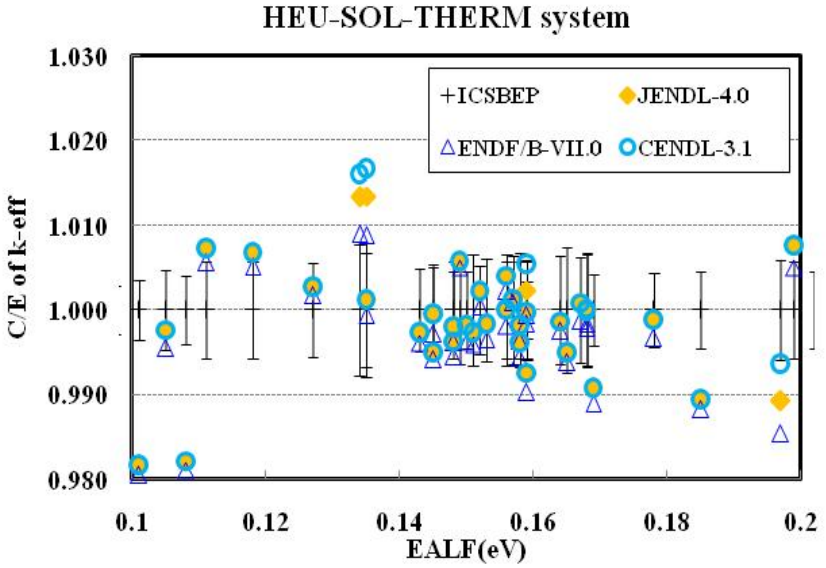
1. Revise the thermal energy region data of U-235
   - Information from thermal benchmark testing
   - Modification of thermal data
   - Testing of revised U-235
   - Comments
2. Preliminary evaluation of $^{235}U(n,\gamma)$ XS in keV energy region
   - Background
   - Review the experimental data of alpha
   - Comparing effects of two different alpha evaluations
   - Comments

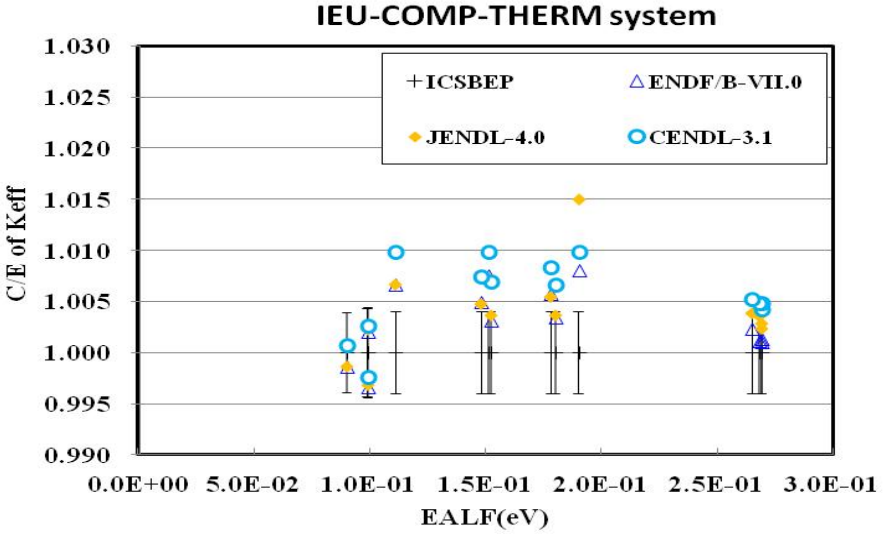
1.1 Information from thermal benchmark testing

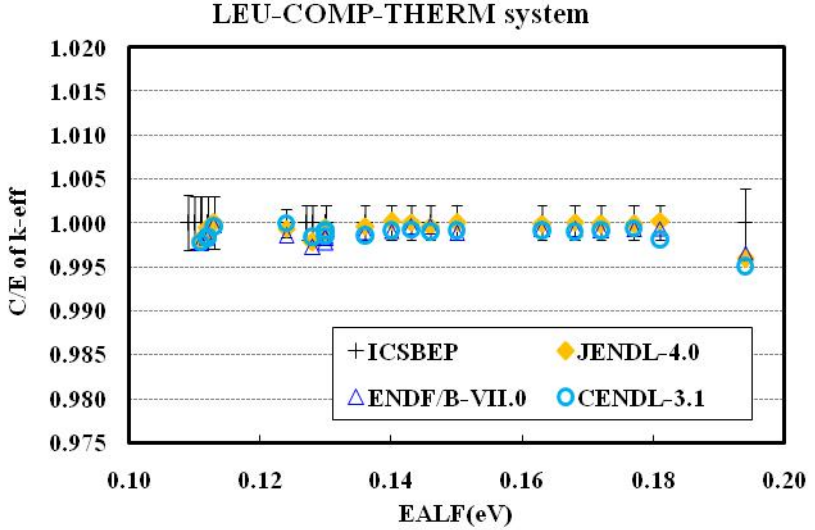
- CENDL-3.1 and others were tested with the following critical benchmarks with EALF between 0.05 and 0.2eV.
  - HEU-MET-THERM : HMT1.1, 6.1~18, 8, 9, 10, 11.1~43, 12, 13, 14, 15, 16, 18, 22, 31;
  - HEU-SOL-THERM : HST9.3, 17.2~8,18.1~4, 28.9~18, 29.1~7, 30.4~7;
  - IEU-COMP-THERM : ICT1;
  - LEU-COMP-THERM : LCT1,2,3.22, 4.10, 6, 7,14,18, 26(1,3,5), 48.

- Over predictions of C/E values of k_{eff} are found in HEU and IEU thermal system.
  - The results of the LCT system are very good at the same time.

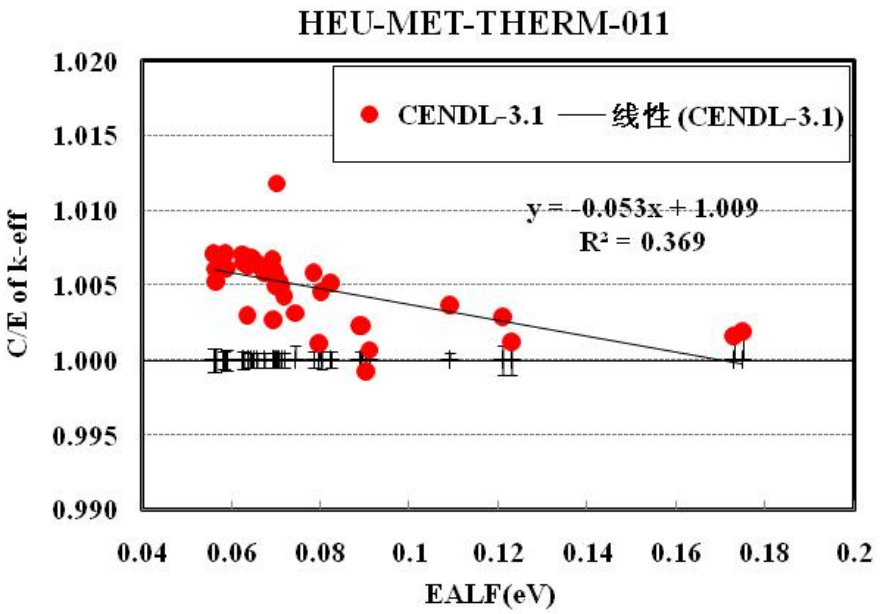

HEU-MET-THERM system
C/E of k-eff
EALF(eV)
JENDL-4.0
ENDF/B-VII.0
CENDL-3.1

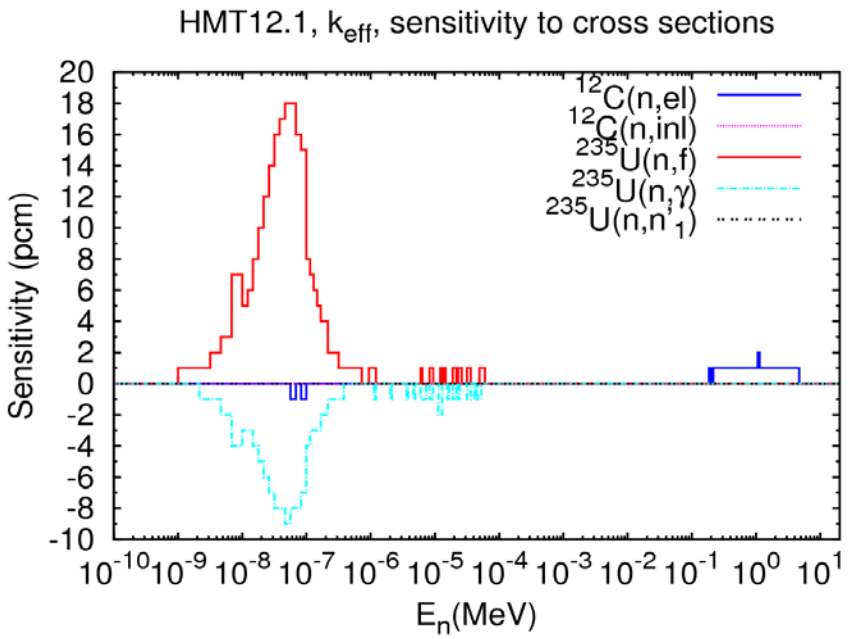

HEU-SOL-THERM system
C/E of k-eff
EALF(eV)
+ICSBEP
JENDL-4.0
ENDF/B-VII.0
CENDL-3.1


IEU-COMP-THERM system
C/E of Keff
EALF(eV)
+ICSBEP
ENDF/B-VII.0
JENDL-4.0
CENDL-3.1

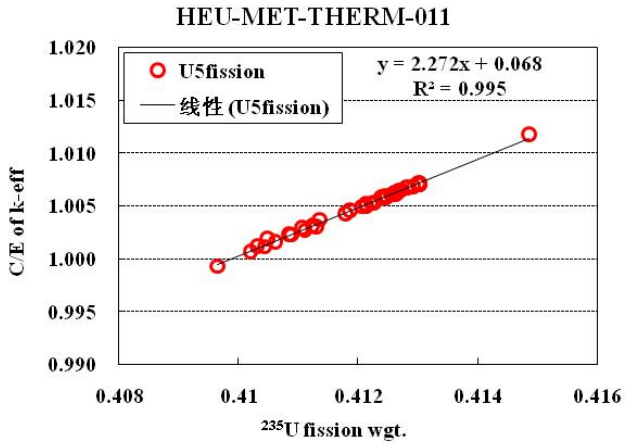

LEU-COMP-THERM system
C/E of k-eff
EALF(eV)
+ICSBEP
JENDL-4.0
ENDF/B-VII.0
CENDL-3.1

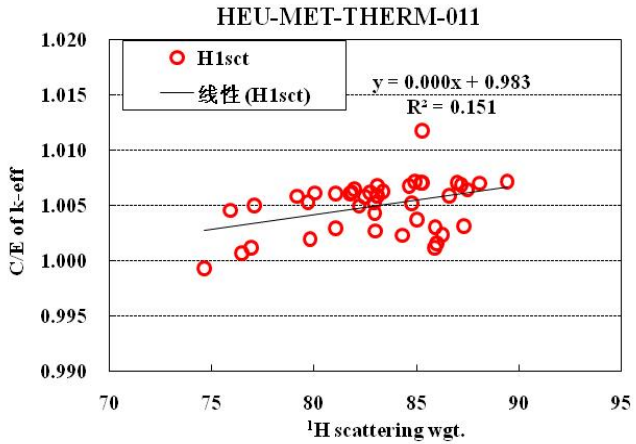
- k_{eff} Bias depend on the spectra is found if only the results of HMT11 are plotted.
- $^{235}U(n,f)$ and (n,γ) cross sections around 0.0253eV.

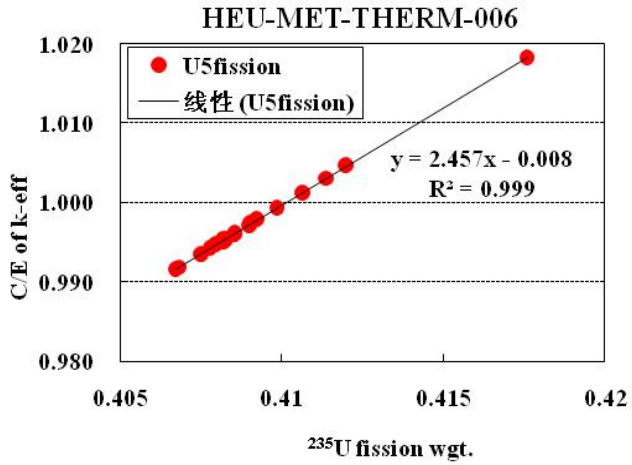


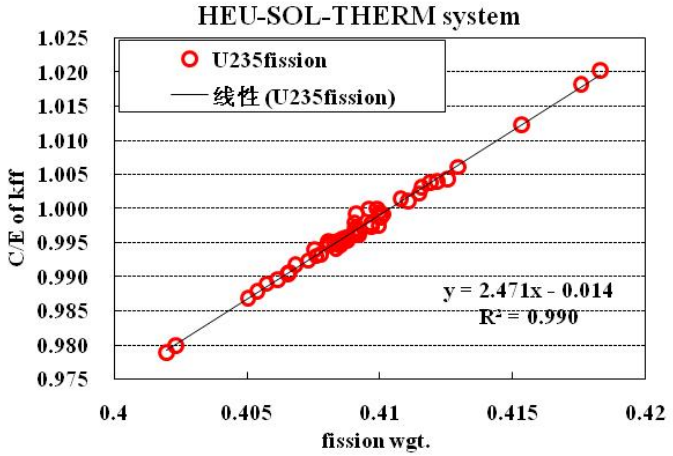


- The bias of the C/E values are strong correlated with ^{235}U fission reaction in the HMT and HST cores, but not $^{1}H(n, el)$.









The improvement of (n,f), (n,g) XS and nubar in thermal region are expected.

1.2 Modification of thermal data

- CENDL-3.1 vs. IAEA2006 standard
  - ✓ Small uncertainties for adjustment is available.

	IAEA2006			CENDL-3.1	Eval./Std.
	Standard	Abs.Err	Re.Err.		
Fission	584.33b	1.02b	±0.175%	585.081	**0.13%**
Capture	99.401b	0.719b	±0.723%	98.7064	**-0.70%**
Elastic	14.087b	0.2197b	±1.560%	15.1153	7.30%
nubar	2.4355	0.0023	±0.094%	2.4367	**0.05%**

- **α** and **η** values of U-235 in thermal region have direct influence on k_{eff} calculation.

$$\alpha \equiv \sigma_\gamma / \sigma_f \qquad \eta \equiv \bar{\nu}\frac{\sigma_f}{\sigma_a} = \frac{\bar{\nu}}{(1+\alpha)} \qquad k_\infty = \varepsilon p f \eta$$

	IAEA2006			CENDL-3.1	Eval./Std.
	Standard	Abs.Err	Re.Err.		
η	2.0814	0.0156	±0.750%	2.0850	**0.17%**
α	0.1701	0.0013	**±0.744%**	0.1687	**-0.83%**

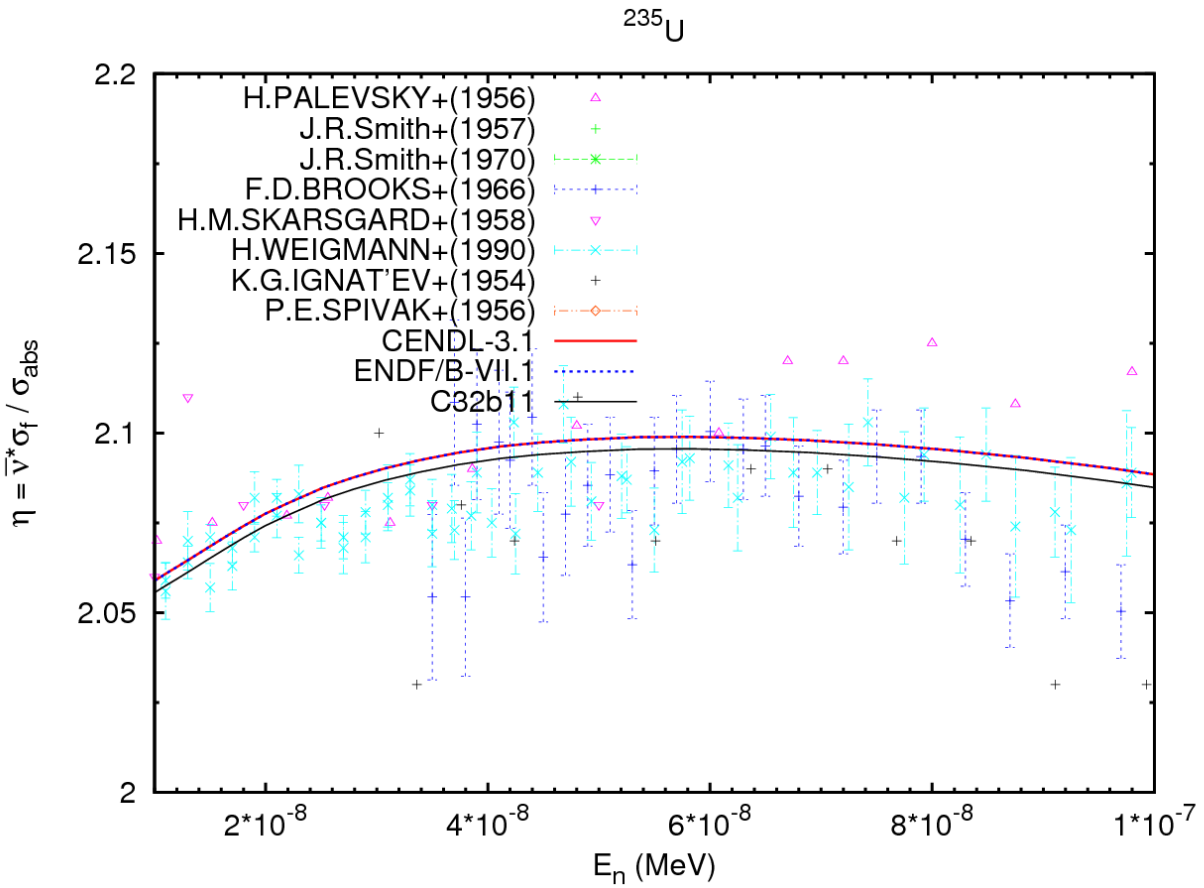
- Principle of modifications to thermal data
  - Nubar
    - the overall over prediction of k_{eff} from HMT and HST system can be adjusted by reduce nubar. But the reduction should be very small to avoid damage the good results of the LCT system.
  - Resonance parameters (cross sections) in thermal region
    - To remove the spectra bias, the slope of η curve need to be improved.
    - To decrease overestimation of C/E values, increase capture and reduce fission XS were expected, especially below thermal energy.
    - The adjustments should be limited inside the uncertainty margin.

- IAEA2006 standard at thermal point was taken as a reference.

- C32b11, a test revision of U-235 is obtained with modified nubar and resonance parameters to reproduce the thermal quantities of the IAEA 2006 standard.

Thermal quantities	IAEA2006 standard	CENDL-3.1 evaluation	CENDL-3.1 Eval./Std.	C32b11 evaluation	C32b11 Eval./Std.	Δ
(n,f)	584.33	5.85081E+02	0.13%	5.84177E+02	**-0.03%**	-0.15%
(n,γ)	99.401	9.87064E+01	-0.70%	9.94001E+01	**0.00%**	**0.70%**
(n,el)	14.087	1.51153E+01	7.30%	1.51081E+01	7.25%	-0.05%
(n,tot)	697.818	6.98903E+02	0.16%	6.98685E+02	**0.12%**	-0.03%
G_f	0.97729	0.97667	-0.06%	0.97667	-0.07%	0.00%
G_γ		0.99118		0.99118		
G_a	0.97881	0.97876	0.00%	0.97878	0.00%	0.00%
ν	2.43550	2.43670	0.05%	2.4359	**0.01%**	-0.03%
η	2.08143	2.08496	0.17%	2.0816	**0.01%**	**-0.16%**
α	0.17011	0.16871	-0.83%	0.17015	**0.03%**	**0.85%**

- **η** curve, before vs. after
  - A small overall reduction was achieved, but no significant variety of the slope was found.

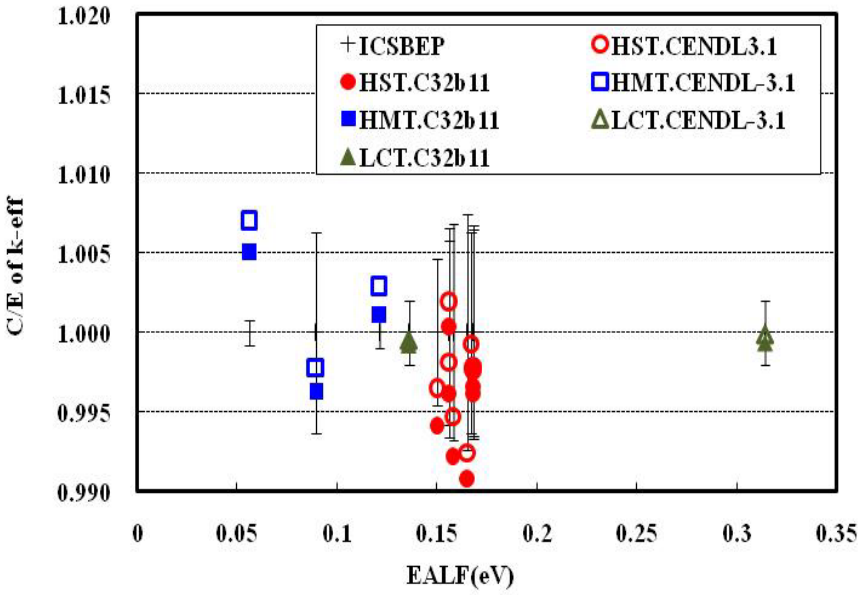


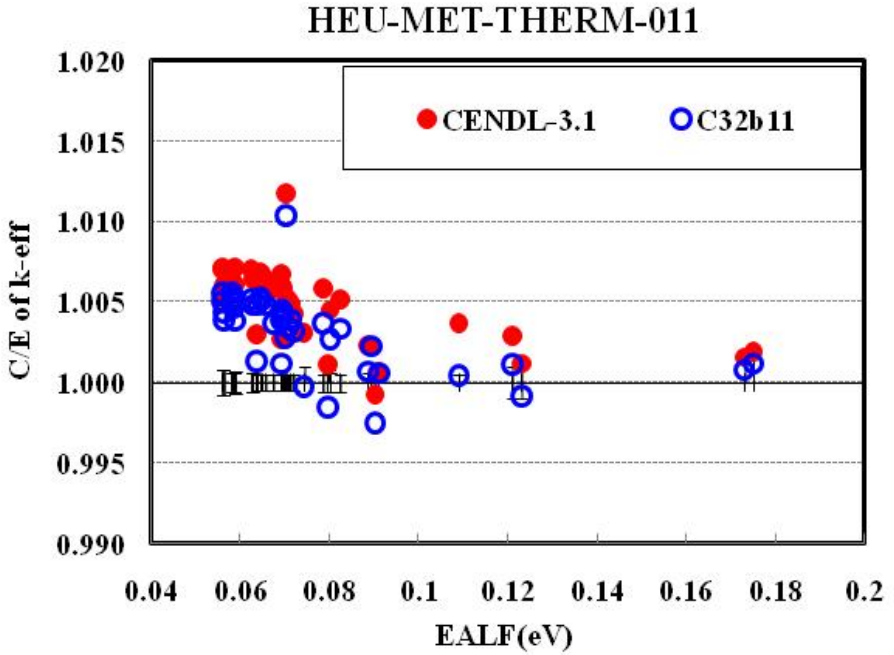
1.3 Testing of revised U-235

- A subset of the former benchmarks is used to test the new data
  - ✓ Only k_{eff} of HEU cores are sensitive to the modification.

Identification	EALF (eV)	k_{eff}	uncertainty (1 sigma)	C/E of k_{eff}		C32b11-C3.1 (pcm)
				CENDL-3.1	C32b11	
HST028_14	0.15	1	0.0046	0.9965	0.9942	-237
HST029_01	0.156	1	0.0066	0.9981	0.9962	-196
HST029_02	0.156	1	0.0058	1.0020	1.0004	-158
HST029_03	0.158	1	0.0068	0.9947	0.9922	-249
HST029_04	0.165	1	0.0074	0.9924	0.9908	-162
HST029_05	0.168	1	0.0067	0.9977	0.9966	-108
HST029_06	0.168	1	0.0065	0.9979	0.9962	-171
HST029_07	0.167	1	0.0063	0.9993	0.9977	-155
HMT009_01	0.0892	1.0032	0.0063	0.9978	0.9963	**-150**
HMT011_01	0.121	1	9.60E-04	1.0029	1.0011	**-176**
HMT011_29	0.056	1	7.90E-04	1.0071	1.0051	**-200**
LCT006_03	0.314	1	0.002	0.9999	0.9994	**-53**
LCT006_14	0.136	1	0.002	0.9995	0.9992	**-34**

- Comparison of benchmark results
  - For both HST and HMT system, 170pcm reduction of C/E values in average is observed, but for some of HSTs C/E values move out of uncertainty bar.
  - No significant changes for LCT system.
  - For HMT11, the reduction of k_{eff} for a core with softer spectrum is larger than that of core with harder spectrum.





1.4 Comments

- By adjusting the nubar and R.P. in thermal region, a revision of U-235 evaluation is obtained, with thermal quantities more close to IAEA 2006 standard.
- The C/E values of HMT system, like HMT011, are reduced 170pcm in average and good prediction of k_{eff} for LCT system is reserved at the mean time.
- Inconsistence between the results of HMT and HST need to be study in future.
- To eliminate the k_{eff} bias of HMT11, nuclear data such as the resolved resonance parameters for U-235 still needs further study.

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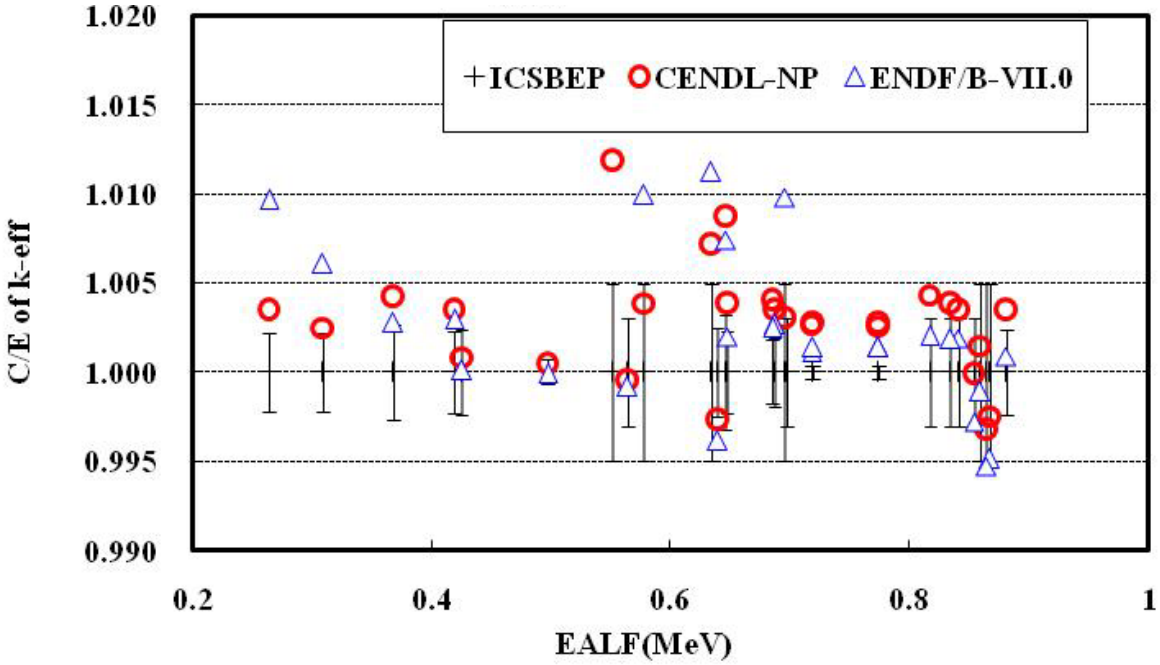
2.1 Background

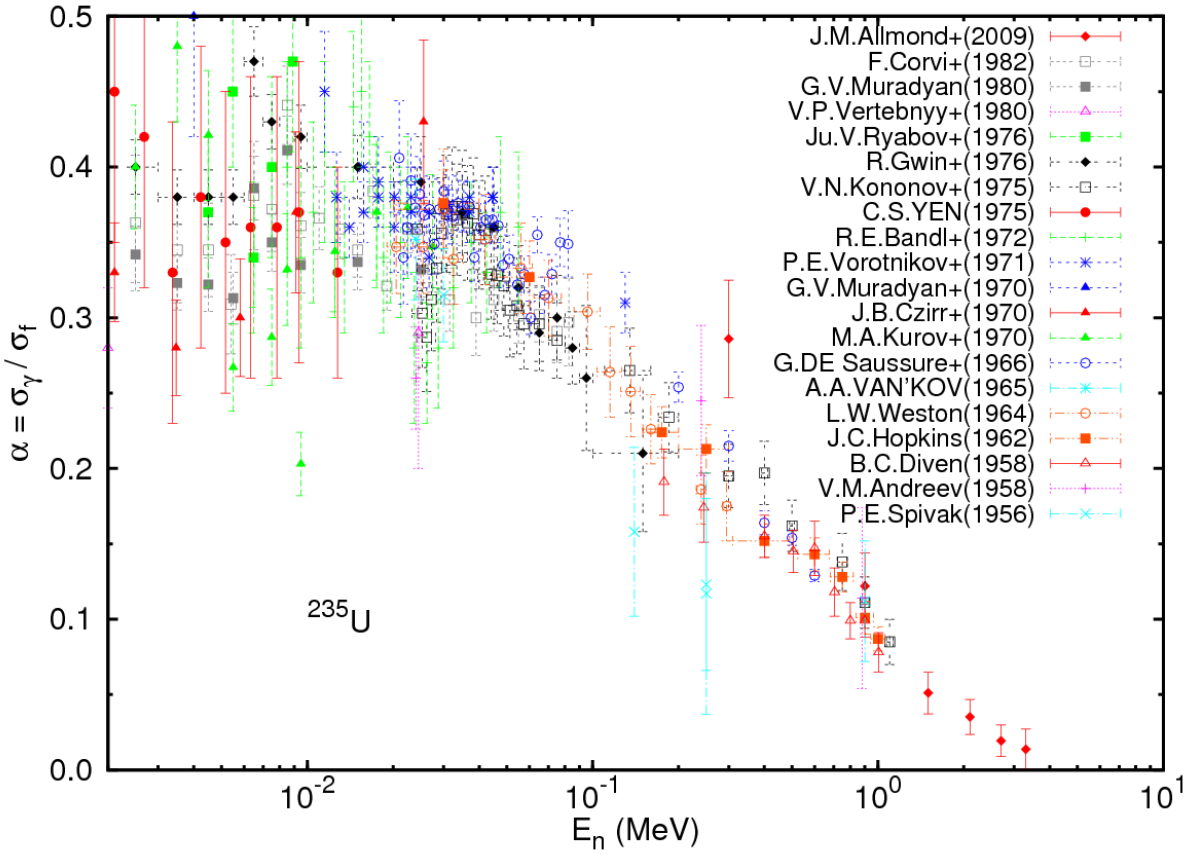
- In benchmarking of CENDL-NP with selected HMF, IMF and HMI cores, 300 pcm over prediction of C/Es in average was found.
  - CENDL-NP is a hybrid library with C31/^{235}U, B70/^{238}U, B71/Al, B71/Cr included.
  - HMF1,3,4,48, IMF1~10,12~14 and HMI1,6.



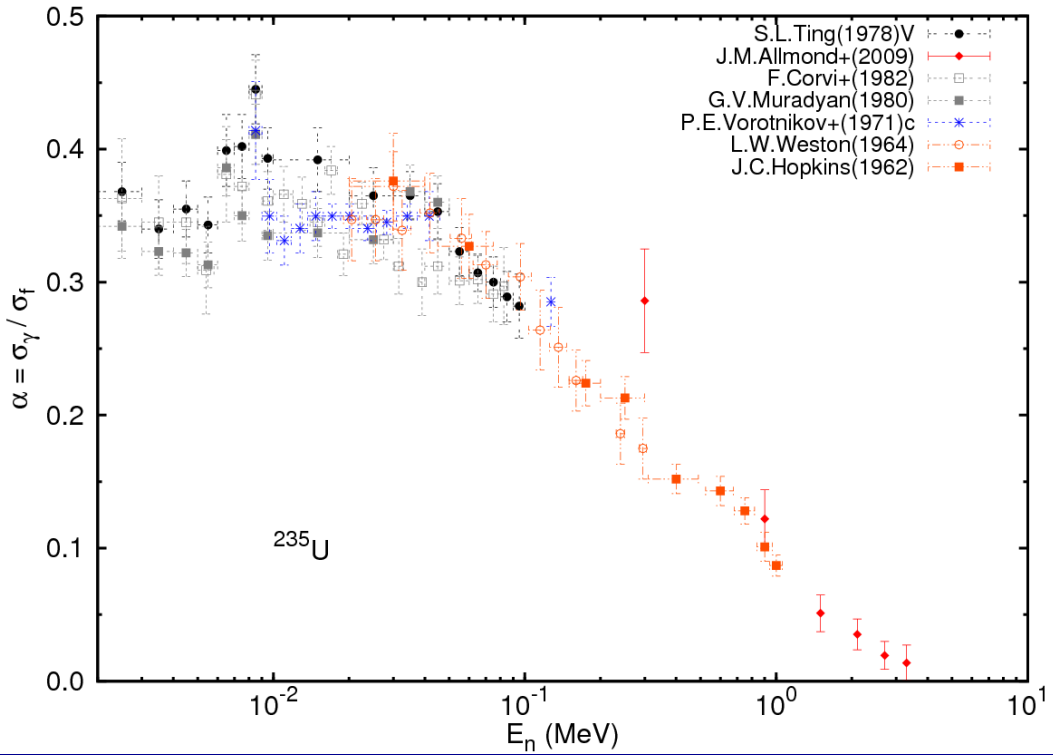
- Luis Leal mentioned in his presentation:
  - "The capture cross section is deduced from α(U-235) by using the fission cross section recommended by the standard group of IAEA."
  - " Below 100 keV, the capture cross section seems to be consistent with the older « evaluation » work of Zhong (1978). "
- Zhong' evaluation was based on Xunliang Ding(1978)'s α value evaluation in keV energy region.
- From 2.25 to 100keV, (n,γ) cross section of C31/U-235 is based on α evaluation and an old fission standard.
- After Ding' evaluation there were several set of new experimental data for α.
- It is necessary to re-evaluate the α values to improve the (n,γ) cross section and k_{eff} for INTER and FAST systems . And it is also interesting to test Ding's α evaluation.

2.2 Review the experimental data of alpha

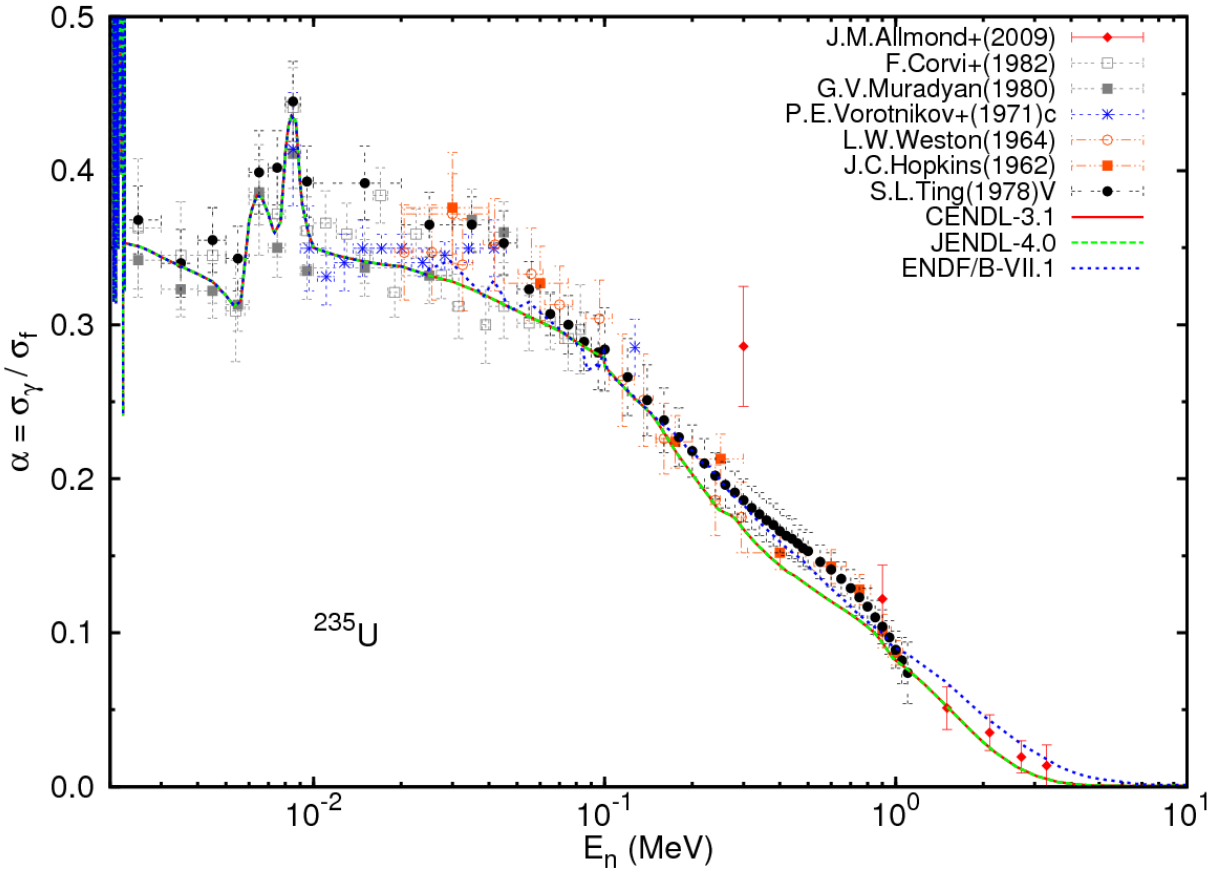
- From 1keV to 4MeV, all available data in EXFOR are investigated and most of them are plotted in figure below.



- Ding's evaluation vs. the selected experimental data
  - The older experimental data from the same author and the experimental data with too large uncertainties are removed.
  - Vorotnikov(1971)' data was renormalized with the integral (n, abs) cross section from 29 to 34 keV, which was deduced from Murandyan(1980) experiment.

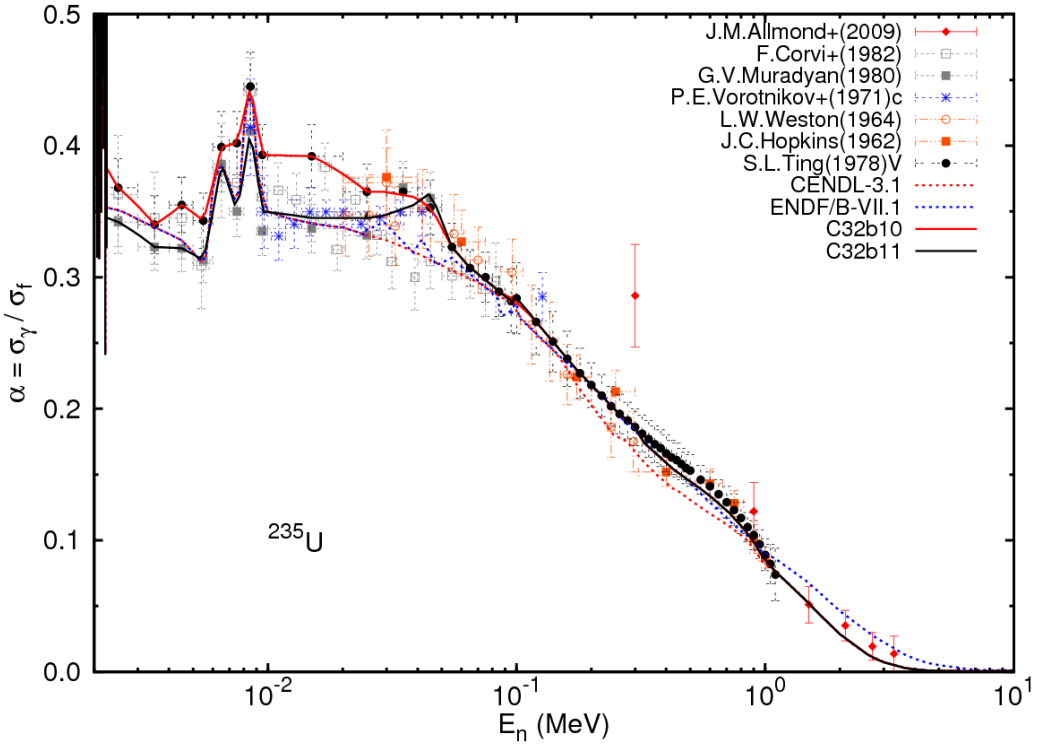


- Comparison of CENDL-3.1, ENDF/B-VII.0 and JENDL-4.0 with the selected experimental data
  - C31 and J40 share the same alpha values.
  - Above 100keV, B71 is higher than C31.
  - All alpha values deduced from evaluation libraries are lower than Ding's evaluation.

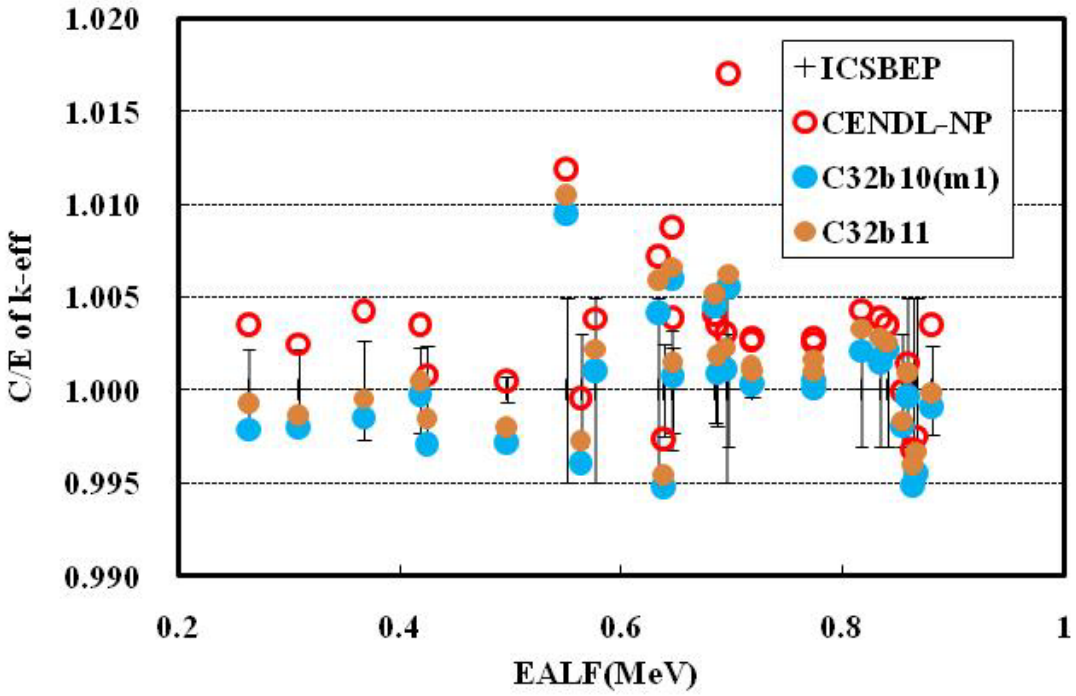


2.3 Comparing effects of two different alpha evaluations

- Below 100keV, C32b10 follows Ding's evaluation, and C32b11 is evaluated based on Murandyan(1980) and Vorotnikov(1971).
- Between 100~500keV, follows B71.
- Between 500~1000keV, a bit larger values than B71 were used.



- The two test file were tested with selected benchmarks.
- Decrease of C/E values were observed in the results of both evaluations.
  - For EALF < 0.4MeV, the trend of C/E changes is expected, and C32b11 looks better.
  - For EALF > 0.65MeV, C32b10 looks better.



2.4 Summary

- Two trial revisions were made based on the preliminary reviewed alpha experimental data and Ding's evaluation .

- With the new alpha values, the benchmarking results of the selected FAST and INTER spectra cores show some good potential of improving $^{235}U(n,\gamma)$ cross section, but more detail work still needs to be down to get a better evaluation of **α**.

- Sensitivity profiles are need to be calculated in next step to obtain better understanding of the benchmarking results.

- Ratio values, such as **α** and **η**, are more important than the absolute cross sections for criticality calculation.

Thank you for your attention !