On the Validation of New Evaluations for U-235

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May 2015

Background

The Working Party on Evaluation Cooperation of the OECD set up a subgroup WPEC-SG40 (alias CIELO) to focus on the evaluated nuclear data of the major nuclides in reactor technology, namely ^{1}H, ^{16}O, ^{56}Fe, ^{235}U, ^{238}U and ^{239}Pu. Different research groups in various parts of the world are working on improved evaluated nuclear data and their uncertainties for these nuclides; the ultimate test of improvement is the performance of the data in simulating integral experiments.

The Coordinated Research Project (CRP) is in progress at the Nuclear Data Section (NDS) of the International Atomic Energy Agency with the objective to investigate the differential and integral experimental data on the prompt fission neutron spectra (PFNS) of actinides. Some information on the selection of experimental data for the analysis is available in [1] Additionally, in the on-going neutron standard project it is planned to include ^{235}U PFNS induced by thermal neutrons as a reference neutron field.

Within the on-going IAEA CRP on input model parameters (RIPL), Lane-Consistent Coupled-Channel Dispersive Optical Model Parameters for the actinides have been produced. This was the starting point for the EMPIRE calculations for ^{235}U to produce cross section data above the resonance range.

As an alternative, a new evaluation of the cross sections above the resonance range (version 1.4) by P. Romain et al. from Bruyeres-le-Chatel (BRC) was offered to the CIELO project. The evaluation features the thermal-neutron induced PFNS with an average energy of 1.97 MeV and an increased capture cross section above the resonance range up to about 0.1 MeV.

An updated set of resonance parameters was produced by L. Leal from the Oak Ridge National Laboratory.

The fission cross section is a standard from 0.15 MeV to 20 MeV. The data in the ENDF/B-VII.1 library are consistent with the Standards.

The data sources listed above were used to assemble full evaluated data files for ^{235}U that were tested.

File description

The evaluated data file from BRC was adopted without changes, since it already included the new ORNL resonance data. In the present analysis this file is referred to with the label “u235o4brc2”.

The IAEA file was assembled from the output of the EMPIRE. The fission data were replaced by the data from the ENDF/B-VII.1 library. The EMPIRE calculation reproduces the fission cross section of the Standards very well, but to avoid any “noise” in the results from small differences, the fission cross section from ENDF/B-VII.1 was adopted throughout. Fission spectrum models have no impact on the cross sections. For simplicity, the delayed neutron data and the prompt fission spectra (PFNS) at high energies were taken from the ENDF/B-VII.1 library. The PFNS induced by thermal neutrons was taken from the GMA combined fit, which is proposed for the new release of Standards, The PFNS for incident neutrons from 0.5 MeV to 2 MeV was taken from the GANDR fit performed at the IAEA based on available differential data. The GMA fit of the PFNS differs very slightly from the GANDR fit for incident thermal neutrons. The impact on integral benchmarks due to the differences is very small in most cases. The capture cross section calculated by EMPIRE lacks some fine tuning; for the time being the capture cross section from JENDL-4 was adopted, but this has very little impact on the internal consistency of the calculations, since the capture cross section at high energies is a minor reaction channel. The IAEA evaluation is referred to with the label “u235ib02o4g6a”.

In summary, the following files are included in the analysis:

e71	Original ^{235}U evaluation from ENDF/B-VII.1.
u235o4brc2	Evaluation by P. Romain from BRC with resonance data from ORNL.
u235ib02o4g6a	IAEA evaluation with resonance data from ORNL.

The evaluated data files described above were processed with NJOY2012 to prepare ACE libraries with which the selected benchmark assemblies were modelled.

Results

The 235U is the primary fuel material, therefore practically all criticality benchmarks are affected, except those fuelled by ^{239}Pu of ^{233}U. For this reason a scoping study was made, including a very large number of benchmarks, which were deemed highly sensitive to the ^{235}U data. The list is split into groups by certain common characteristics, as evident from Tables 1a-1g. The results are shown in Figures 1a-1g.

In the list of benchmarks including thorium the IEU-COMP-THERM-005 (alias KBR-21) benchmark could be included, but it is such a big outlier and marginally sensitive to ^{235}U data that it was decided to exclude it from analysis. There are also additional benchmarks from the HEU-COMP-THERM-021 series, but they do not provide any additional insight, so they were also excluded. Similarly in the list of benchmarks including zirconium the IEU-COMP-INTER-005 (alias KBR-16) benchmark could be included, but it is a big outlier so it was excluded from the analysis. The HEU-MET-FAST-072 series (alias ZEUS cores) were excluded because we have doubts about the copper data, which could bias the conclusions.

Table 1a: List of most commonly used uranium benchmarks.

	ICSBEP Name	Short name	Common name
1	HEU-MET-FAST-001	hmf001	Godiva
2	HEU-MET-FAST-028	hmf028	Flattop-25
3	IEU-MET-FAST-007	imf007d	Big_Ten(detailed)
4	HEU-MET-FAST-002	hmf002-1	Topsy-1
5	HEU-MET-FAST-002	hmf002-2	Topsy-2
6	HEU-MET-FAST-002	hmf002-3	Topsy-3
7	HEU-MET-FAST-002	hmf002-4	Topsy-4
8	HEU-MET-FAST-002	hmf002-5	Topsy-5
9	HEU-MET-FAST-002	hmf002-6	Topsy-6
10	IEU-MET-FAST-001	imf001-1	Jemima-1
11	IEU-MET-FAST-001	imf001-2	Jemima-2
12	IEU-MET-FAST-001	imf001-3	Jemima-3
13	IEU-MET-FAST-001	imf001-4	Jemima-4
14	MIX-MET-INTER-004	mmi004	ZPR-3/53
15	IEU-MET-FAST-002	imf002	Pajarito
16	HEU-COMP-INTER-003	hci003-1	COMET-UH3-1
17	HEU-COMP-INTER-003	hci003-4	COMET-UH3-4
18	HEU-COMP-INTER-003	hci003-6	COMET-UH3-6
19	HEU-COMP-INTER-003	hci003-7	COMET-UH3-7

Table 1b: List of additional uranium benchmarks.

	ICSBEP Name	Short name	Common name
1	HEU-MET-FAST-008	hmf008	VNIIEF-CTF-bare
2	HEU-MET-FAST-014	hmf014	VNIIEF-CTF-DU
3	HEU-MET-FAST-032	hmf032-1	COMET-TU1_3.93in
4	HEU-MET-FAST-032	hmf032-2	COMET-TU2_3.52in
5	HEU-MET-FAST-032	hmf032-3	COMET-TU3_1.742in
6	HEU-MET-FAST-032	hmf032-4	COMET-TU4_0.683in
7	IEU-MET-FAST-003	imf003-2	VNIIEF-CTF-3
8	IEU-MET-FAST-004	imf004-2	VNIIEF-CTF-4
9	IEU-MET-FAST-005	imf005-s	VNIIEF-CTF-5s
10	IEU-MET-FAST-006	imf006-s	VNIIEF-CTF-6s
11	IEU-MET-FAST-010	imf010	ZPR-6/9(U9)
12	LEU-COMP-THERM-008	lct008-01	BW-XI-1
13	LEU-COMP-THERM-008	lct008-02	BW-XI-2
14	LEU-COMP-THERM-008	lct008-05	BW-XI-5
15	LEU-COMP-THERM-008	lct008-07	BW-XI-7
16	LEU-COMP-THERM-008	lct008-08	BW-XI-8
17	LEU-COMP-THERM-008	lct008-11	BW-XI-11

18	LEU-SOL-THERM-002	lst002-1	ORNL-UO2F2
19	LEU-SOL-THERM-002	lst002-2	ORNL-UO2F2
20	LEU-SOL-THERM-007	lst007-14	STACY-14
21	LEU-SOL-THERM-007	lst007-30	STACY-30
22	LEU-SOL-THERM-007	lst007-32	STACY-32
23	LEU-SOL-THERM-007	lst007-36	STACY-36
24	LEU-SOL-THERM-007	lst007-49	STACY-49

Table 1c: List of highly-enriched thermal solution benchmarks.

	ICSBEP Name	Short name	Common name
1	HEU-SOL-THERM-009	hst009-1	ORNL_S1
2	HEU-SOL-THERM-009	hst009-2	ORNL_S2
3	HEU-SOL-THERM-009	hst009-3	ORNL_S3
4	HEU-SOL-THERM-009	hst009-4	ORNL_S4
5	HEU-SOL-THERM-013	hst013-1	ORNL_T1
6	HEU-SOL-THERM-013	hst013-2	ORNL_T2
7	HEU-SOL-THERM-013	hst013-3	ORNL_T3
8	HEU-SOL-THERM-013	hst013-4	ORNL_T4
9	HEU-SOL-THERM-032	hst032	ORNL_T5
10	HEU-SOL-THERM-001	hst001-01	R01
11	HEU-SOL-THERM-001	hst001-02	R02
12	HEU-SOL-THERM-001	hst001-03	R03
13	HEU-SOL-THERM-001	hst001-04	R04
14	HEU-SOL-THERM-001	hst001-05	R05
15	HEU-SOL-THERM-001	hst001-06	R06
16	HEU-SOL-THERM-001	hst001-07	R07
17	HEU-SOL-THERM-001	hst001-08	R08
18	HEU-SOL-THERM-001	hst001-09	R09
19	HEU-SOL-THERM-001	hst001-10	R10
20	HEU-SOL-THERM-042	hst042-1	ORNL_C1
21	HEU-SOL-THERM-042	hst042-2	ORNL_C2
22	HEU-SOL-THERM-042	hst042-3	ORNL_C3
23	HEU-SOL-THERM-042	hst042-4	ORNL_C4
24	HEU-SOL-THERM-042	hst042-5	ORNL_C5
25	HEU-SOL-THERM-042	hst042-6	ORNL_C6
26	HEU-SOL-THERM-042	hst042-7	ORNL_C7
27	HEU-SOL-THERM-042	hst042-8	ORNL_C8

Table 1d: List of benchmarks containing thorium.

	ICSBEP Name	Short name	Common name
1	HEU-COMP-THERM-015	hct015-11	SB-1
2	HEU-COMP-THERM-015	hct015-15	SB-5
3	IEU-COMP-FAST-002	icf002	KBR-18
4	IEU-COMP-INTER-001	ici001-19	KBR-19
5	IEU-COMP-INTER-001	ici001-20	KBR-20

6	HEU-MET-FAST-068	hmf068	KBR-22
7	HEU-MET-INTER-008	hmi008	KBR-23
8	HEU-COMP-THERM-021	hct021-01	TUPE-001
9	HEU-COMP-THERM-021	hct021-02	TUPE-002
10	HEU-COMP-THERM-021	hct021-03	TUPE-003
11	HEU-COMP-THERM-021	hct021-04	TUPE-004
12	HEU-COMP-THERM-021	hct021-05	TUPE-005
13	HEU-COMP-THERM-021	hct021-06	TUPE-006
14	HEU-COMP-THERM-021	hct021-07	TUPE-007
15	HEU-COMP-THERM-021	hct021-08	TUPE-008
16	HEU-COMP-THERM-021	hct021-13	TUPE-013
17	HEU-COMP-THERM-021	hct021-14	TUPE-014

Table 1e: List of benchmarks containing tungsten and nickel.

	ICSBEP Name	Short name	Common name
1	IEU-MET-FAST-013	imf013	ZPR-9/1
2	IEU-MET-FAST-014	imf014-2	ZPR-9/2
3	IEU-MET-FAST-014	imf014-3	ZPR-9/3
4	HEU-MET-FAST-060	hmf060-4	ZPR-9/4
5	HEU-MET-FAST-067	hmf067-5	ZPR-9/5
6	HEU-MET-FAST-067	hmf067-6	ZPR-9/6
7	HEU-MET-FAST-070	hmf070-7	ZPR-9/7
8	HEU-MET-FAST-070	hmf070-8	ZPR-9/8
9	HEU-MET-FAST-070	hmf070-9	ZPR-9/9
10	HEU-MET-FAST-049	hmf049-1	KFBN2-1cm
11	HEU-MET-FAST-049	hmf049-2	KFBN2-3cm
12	HEU-MET-FAST-049	hmf049-3	KFBN2-8cm
13	HEU-MET-FAST-050	hmf050	KFBN2-f1
14	HEU-MET-FAST-052	hmf052	KFBN2-f2
15	HEU-MET-MIXED-017	hmm017	KFBN2-f3
16	HEU-MET-FAST-084	hmf084-14	Comet-W_1.0in
17	HEU-MET-FAST-084	hmf084-25	Comet-W_0.5in
18	HEU-MET-FAST-085	hmf085-6	Comet-W_2.0in
19	HEU-MET-FAST-003	hmf003-08	Topsy-W_1.9in
20	HEU-MET-FAST-003	hmf003-09	Topsy-W_2.9in
21	HEU-MET-FAST-003	hmf003-10	Topsy-W_4.5in
22	HEU-MET-FAST-003	hmf003-11	Topsy-W_6.5in
23	HEU-MET-FAST-003	hmf003-12	Topsy-Ni

Table 1f: List of benchmarks containing zirconium.

	ICSBEP Name	Short name	Common name
1	HEU-MET-FAST-061	hmf061	ZPPR-21F
2	HEU-COMP-THERM-007	hct007-1	RRCt-1
3	HEU-COMP-MIXED-003	hcm003-1	RRCm-1
4	IEU-COMP-THERM-003	ict003-1	TRIGA C_132

5	IEU-COMP-THERM-003	ict003-2	TRIGA C_132
6	IEU-COMP-THERM-009	ict009-1	PBF-1
7	IEU-COMP-THERM-009	ict009-2	PBF-2
8	MIX-MET-FAST-011	mmf011-b	ZPPR-21B
9	MIX-MET-FAST-011	mmf011-c	ZPPR-21C
10	MIX-MET-FAST-011	mmf011-d	ZPPR-21D
11	MIX-MET-FAST-011	mmf011-e	ZPPR-21E
12	LEU-COMP-THERM-009	lct009-26	LCT9-26
13	LEU-COMP-THERM-009	lct009-27	LCT9-27

Table 1g: List of benchmarks containing iron.

	ICSBEP Name	Short name	Common name
1	HEU-MET-FAST-013	hmf013	VNIITF-CTF-SS-13
2	HEU-MET-FAST-021	hmf021	VNIITF-CTF-SS-21
3	HEU-MET-FAST-024	hmf024	VNIITF-CTF-SS-24
4	HEU-MET-FAST-087	hmf087	VNIITF-CTF-Fe
5	HEU-MET-FAST-088	hmf088-1	hmf088-1
6	HEU-MET-FAST-088	hmf088-2	hmf088-2
7	HEU-MET-INTER-001	hmi001	ZPR-9/34
8	MIX-COMP-FAST-001	mcf001	ZPR-6/7
9	MIX-COMP-FAST-005	mcf005-s	ZPR-9/31
0	MIX-COMP-FAST-006	mcf006-s	ZPPR-2
11	LEU-COMP-THERM-042	lct042-1	lct042-1
12	LEU-COMP-THERM-042	lct042-2	lct042-2
13	LEU-COMP-THERM-043	lct043-2	IPEN/MB-01
14	HEU-MET-THERM-013	hmt013-2	hmt013-2
15	HEU-MET-THERM-015	hmt015	hmt015

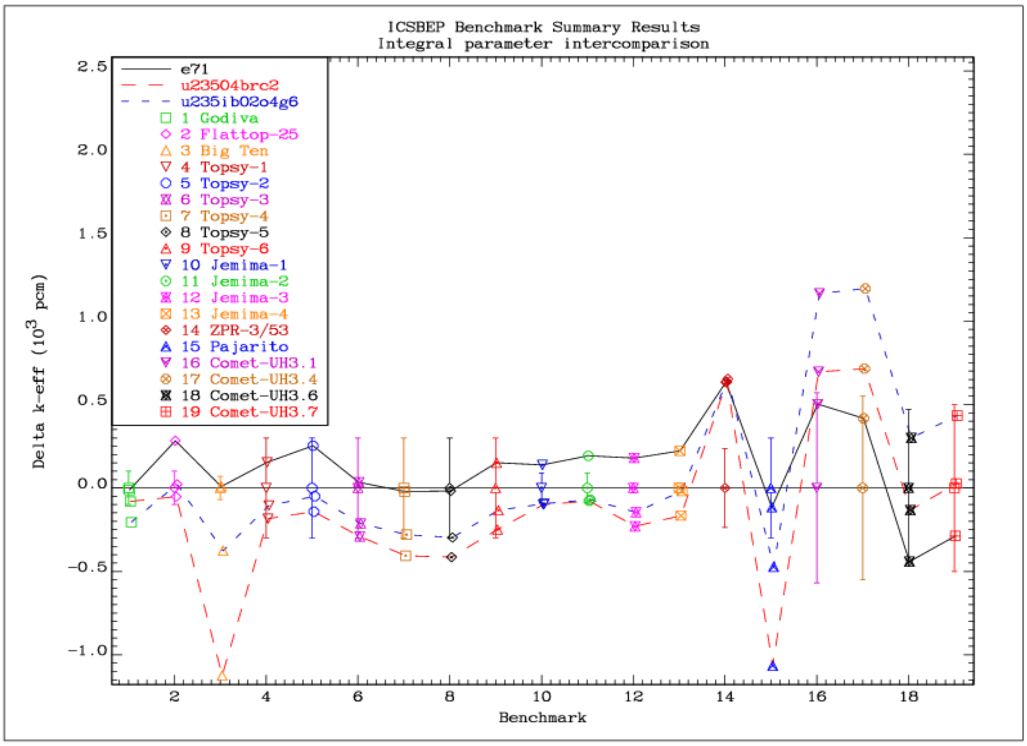

Figure 1a: Results for the list of most commonly used uranium benchmarks.

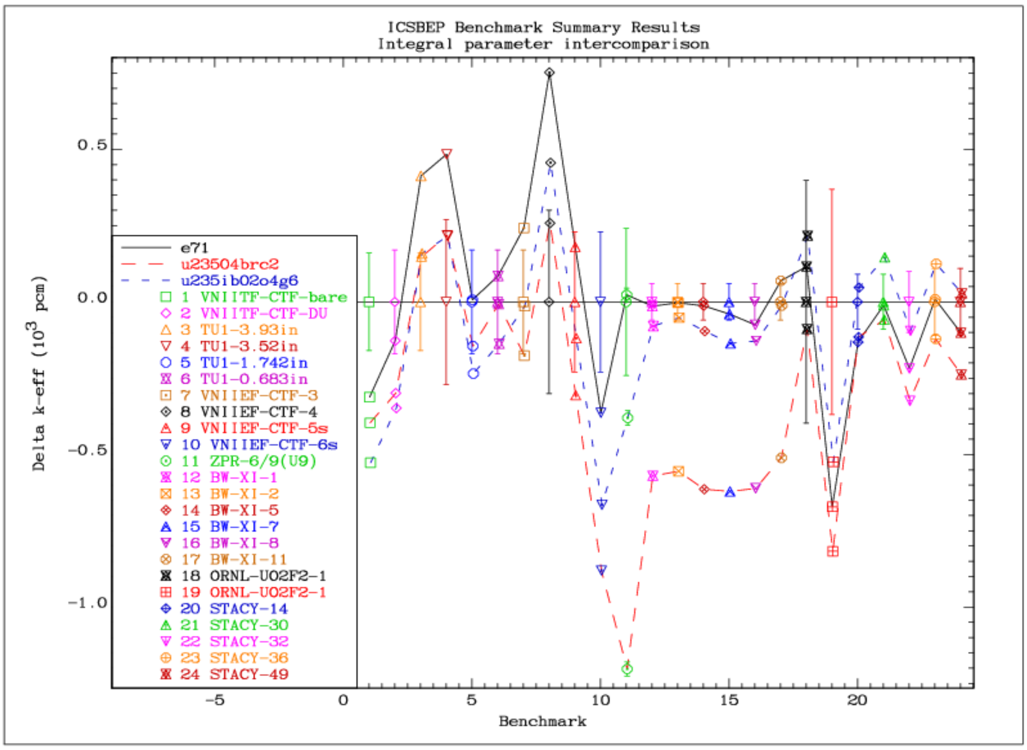

Figure 1b: Results for the list of additional uranium benchmarks.

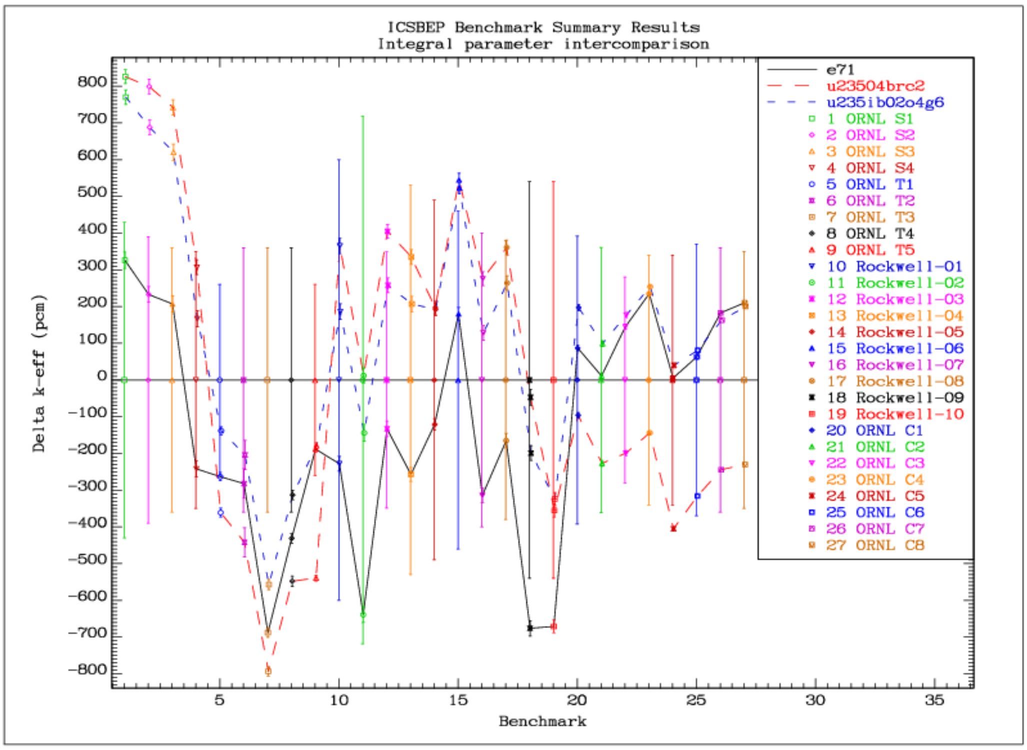

Figure 1c: Results for the list of highly-enriched thermal solution benchmarks.

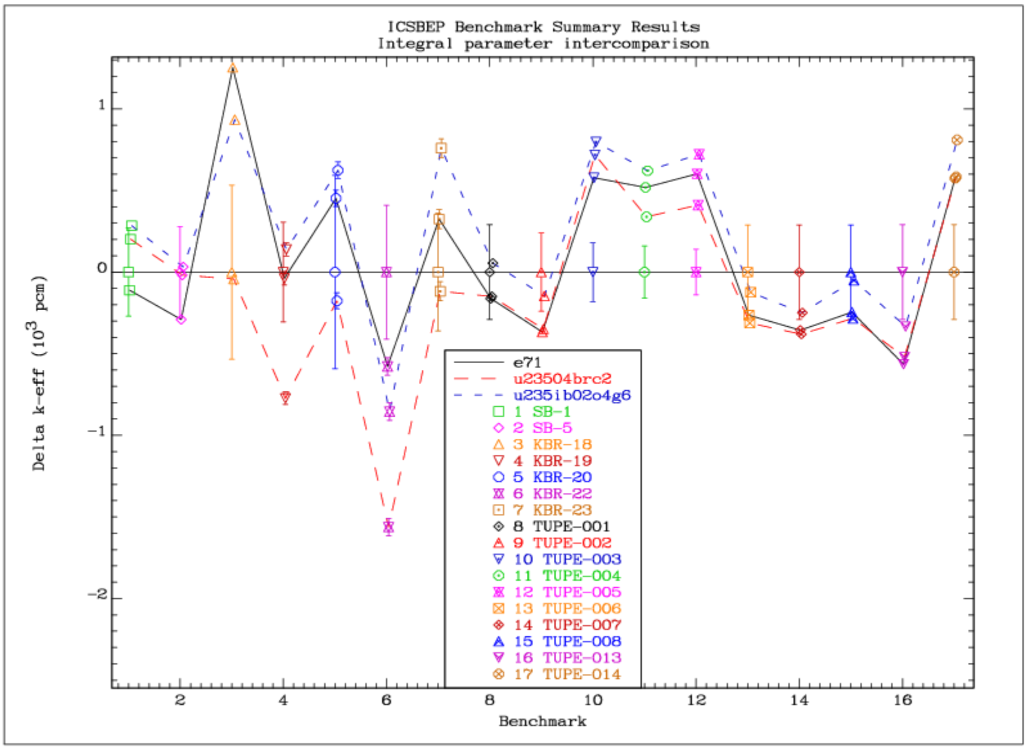

Figure 1d: Results for the list of benchmarks containing thorium.

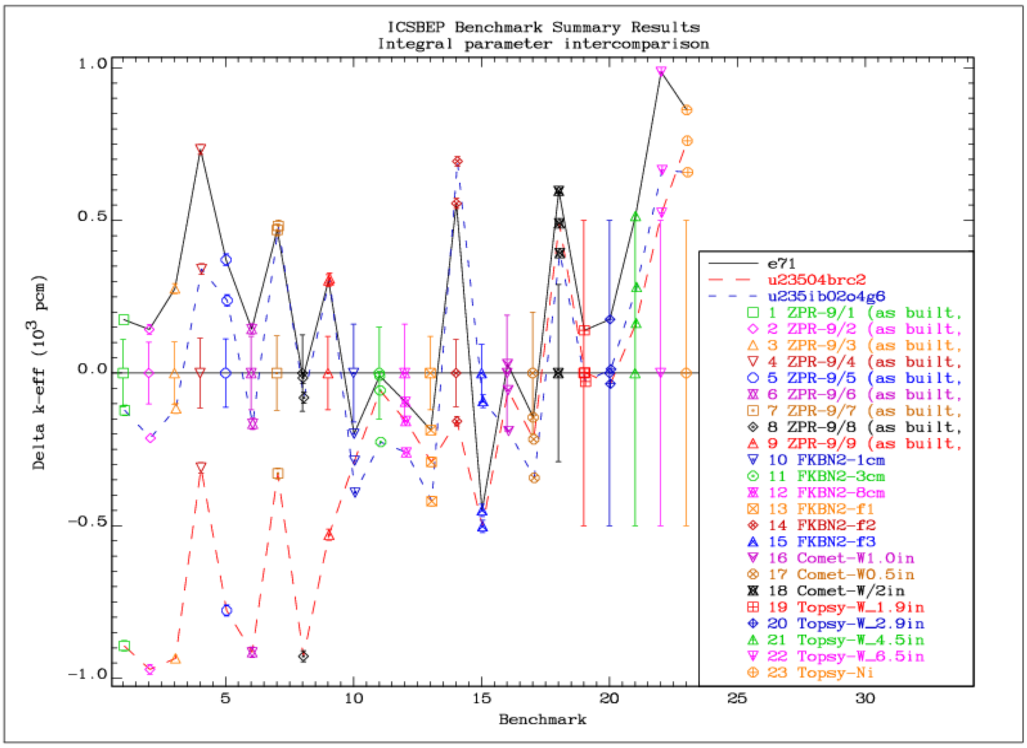

Figure 1e: Results for the list benchmarks containing tungsten and nickel.

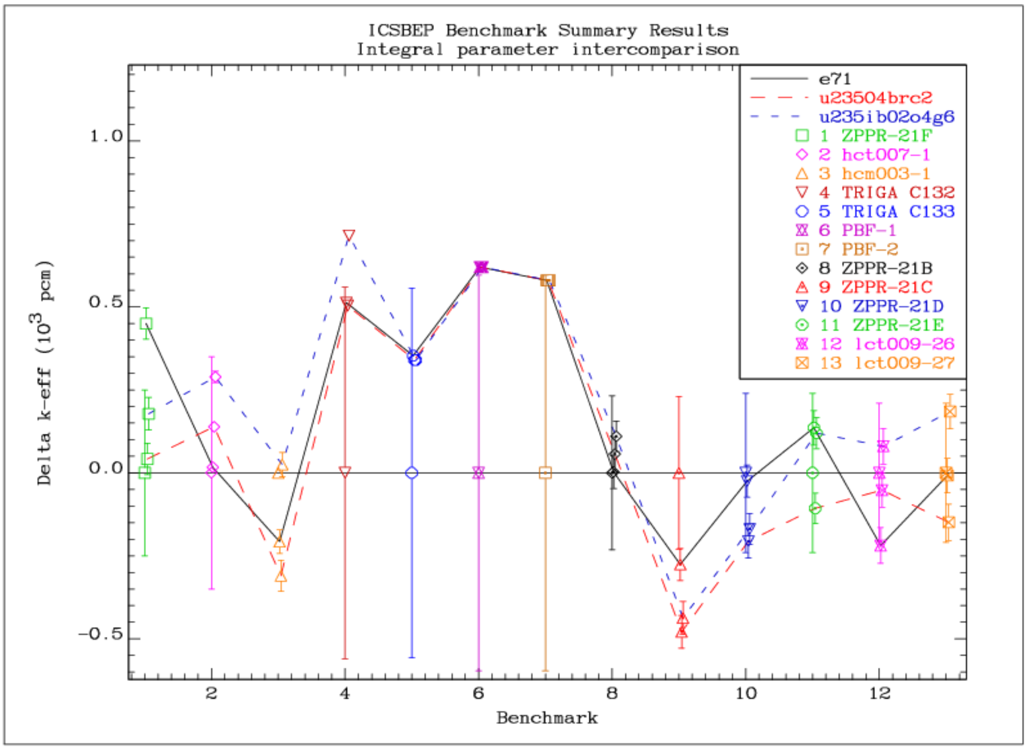

Figure 1f: Results for the list of benchmarks containing zirconium.

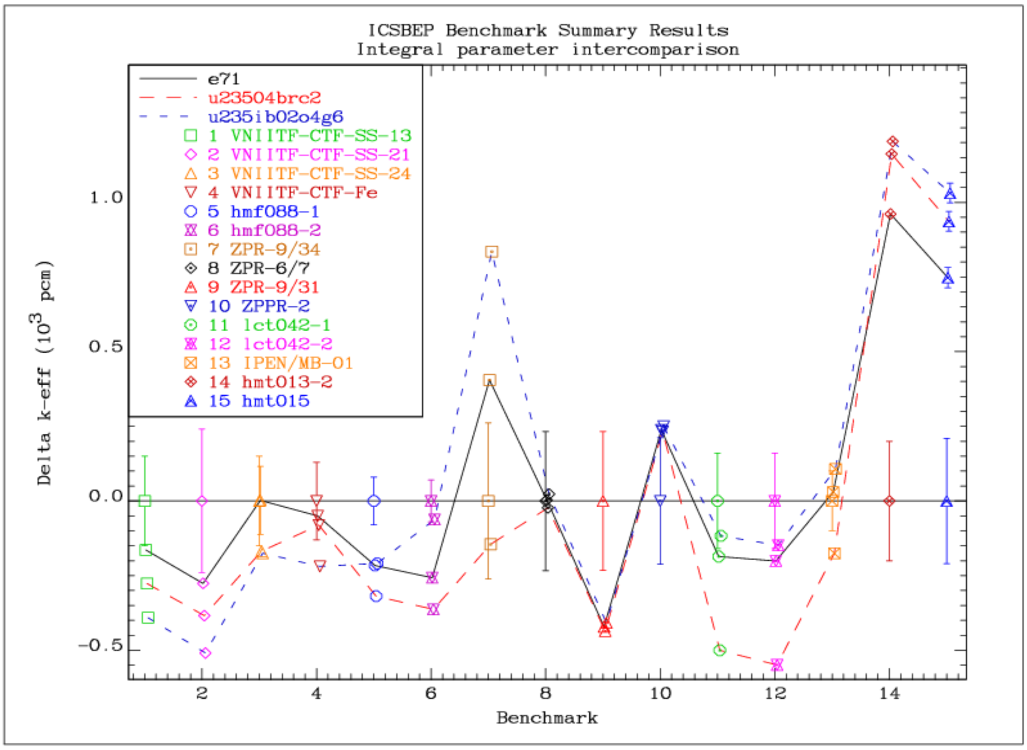

Figure 1g: Results for the list of benchmarks containing iron.

Conclusions

The results need to be analysed carefully. Although there are some benchmarks where the BRC evaluation performs well, we think that the average neutron energy of the thermal-neutron induced PFNS of 1.97 MeV is too low. Also, the large increase in capture above the resonance range needs some justification. The IAEA evaluation seems better on average, but the differences need to be studied more carefully before definite conclusions can be made.

References

[1] A. Trkov: On the Selection of the Differential ^{235}U PFNS Data, International Atomic Energy Agency, Vienna, Austria, December 2014 (unpublished).