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Integral Test of JENDL-3.2 Data by Re-analysis of Sample Reactivity Measurements at SEG and STEK Facilities

Klaus DIETZE
Oarai Engineering Center (OEC)
Japan Nuclear Cycle Development Institute (JNC)
Oarai-machi, Ibaraki-ken, 311-1393
e-mail: dietze@oec.jnc.go.jp

Sample reactivity measurements, which have been performed at the fast-thermal coupled facilities RRR/SEG and STEK, have been re-analyzed using the JNC route for reactor calculation JENDL-3.2 // SLAROM / CITATION / PERKY. C/E-values of central reactivity worths (CRW) of FP nuclides, structural materials, and standards are given.

1. Introduction

Integral tests are necessary to check neutron data and codes used in reactor calculations. Such feedback is very important for evaluators and programmers for data corrections and improvements of the codes. The NEA NSC Working Group on International Evaluation Cooperation proposed to use the STEK and SEG experiments, as a joint data base, for the validation and convergence of the last versions of JENDL, JEF and ENDF/B [1].

At Cadarache (CEA France), extensive re-analyses of the SEG and STEK experiments have been recently completed using the competitive European scheme JEF-2.2 / ECCO / ERANOS [2,3]. The STEK experiments also have been analyzed in Japan [4,5,6], but not the SEG experiments. This paper presents results of a re-analysis of the experiments at SEG and STEK using the JNC route, similar to the European scheme. Additionally, a crisscross use of JEF-2.2 with the JNC route was made for SEG to compare data and routes.

2. Sample Reactivity Measurements

The measurements have been performed with FP nuclides, structural materials, and standards for the central position of the fast-thermal coupled facilities RRR/SEG in Rossendorf/Germany and STEK in Petten/Netherlands using the pile-oscillation method, developed to a high perfection. The specific reactivities of the sample materials were measured over a wide mass range. The sample size corrections and extrapolation to the infinitely dilute (zero mass) value CRW were performed using different methods. Data and codes used in calculations of the self-shielding effect were tested in this manner.

In the STEK configurations, the neutron spectra had an increasing softness covering a broad energy range. A great number of FP nuclides have been measured at STEK. The SEG configurations, however, are characterized by especially designed adjoint spectra to check separately capture and scattering data. In the case of an energy-independent adjoint spectrum, the slowing-down effect disappears and the sample reactivity is due only to absorption. On the other hand, the scattering effect is dominant and negative if the adjoint spectrum is monotonously rising with the energy. The neutron and adjoint spectra of two typical SEG facilities and of the 5 STEK configurations are shown in Fig. 1-3. The SEG experiments are considered as "clean" experiments; i.e., the measurements were performed in simple geometry

under clear conditions well suited for calculation. Only a few materials (most of them are standards) were used in the surrounding of the sample and in the inner core region.

3. Calculations

Cell calculations with SLAROM were performed for all zones using the 70 group library JFS-3 of JENDL-3.2. The pellet filling of the inner regions of the core were treated heterogeneously in slab geometry, the outer regions homogeneously. Then, the neutron and adjoint fluxes were calculated with CITATION (R,Z-geometry) for the critical condition. Finally, perturbation theory calculations were carried out with PERKY (mapping version), providing total and partial reactivity contributions for all reaction types and energy groups. The calculated CRW's were then compared with the extrapolated (infinitely dilute) experimental specific reactivity of the sample material by C/E-ratios.

In order to avoid the determination of the normalization integral of the reactor, the C/E-values were normalized to a reference material, preferably a standard. In most cases boron-10 was used for this. In SEG-6 the scattering effect is dominant; therefore, hydrogen (graphite in the European scheme) was preferred as the reference material. C/E-values were determined for more than 85 materials under investigation at SEG and STEK.

4. Results

Five STEK and five SEG configurations have been analyzed. The calculated maps of reactivity contributions in energy groups can be used to find the main contributions to the total reactivity, in order to locate possible sources of discrepancies in C/E-values.

The C/E-values obtained for STEK are compiled in Table 1. A corresponding table of STEK results obtained with the European scheme is given in [3]. A good agreement was found for standards and for most of the strong absorbers. However, for many weak absorbers more discrepancies were found with an obvious tendency towards a systematic underestimation. This trend was also found in former analyses of STEK [6]. This can be explained by compensating effects of the negative capture and scattering contributions (negative and positive!), due to the dependence of the adjoint spectrum on neutron energy. In fact, the scattering effect is calculated larger by the JNC route than with the European scheme, especially the contribution of the inelastic scattering. For important reactor materials , clear discrepancies were found for Mo-98, Mo-100, Tc-99, Ag-109, Cs-133, Sm-151, Pb, and Pu-240 in nearly all STEK configurations. The 22 most important FP nuclides for fast reactor calculation [7], contributing about 85% to the total reactivity effect of all FP nuclides, are given in the comment column in Table 1.

C/E-values for two typical SEG facilities are compiled in Tables 2 and 3. The results of the JNC route are compared with those of the European scheme [2] and a crisscross use of JEF-2.2 also with the JNC route. The C/E-values for SEG-5 show clear discrepancies for the capture data of Mn, Zr, Mo-95, and Ag-109 (for JENDL-3.2), and of Cd, Mo-95, and Sm-149 (for JEF-2.2). The scattering data of JENDL-3.2 should be checked for Cd, Pb, and Be (Table for SEG-6/45). A significant underestimation was found for Mo-100 in SEG-7A. This can be explained only by inaccurate scattering data.

5. Conclusions

The C/E-values show that uncertainties in JENDL-3.2 (and likewise in JEF-2.2) still exist, especially for structural materials and weak absorbers. Of course, the information is integral; precise corrections should be obtained from adjustment studies.

The certainty of integral tests is limited by the experimental error and by the fact that the calculation must be performed in a few steps. When using different input libraries, codes in the routes, self-shielding treatment, and likewise a different energy group structure, it is difficult to locate exactly the source of the differences and deviations in the C/E-values. Concerning data interpretation, an

additional use of group averaged transmissions has proved useful and could complement integral tests to overcome their specific disadvantages [8].

Integral tests using sample reactivity measurements are not recommendable for materials with a very small reactivity or with large compensating effects. The collapsing from 70 to 18 or 7 energy groups is not recommendable for facilities with soft neutron spectra because of the very broad 18^{th} or 7^{th} energy group (from 10^{-5} up to 100.3 eV). Differences were found between the results in 70 and the results in 18 energy groups [9].

The analyses of this work could easily be repeated for the validation of JENDL-3.3.

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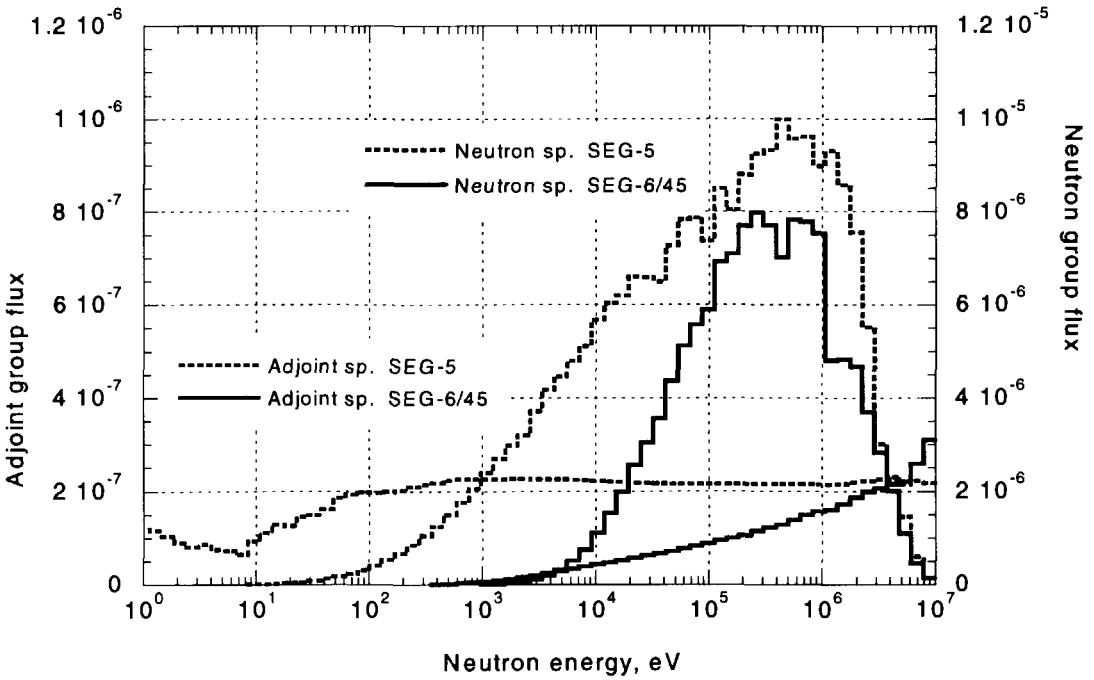

Fig. 1 : Typical neutron and adjoint spectra in SEG facilities

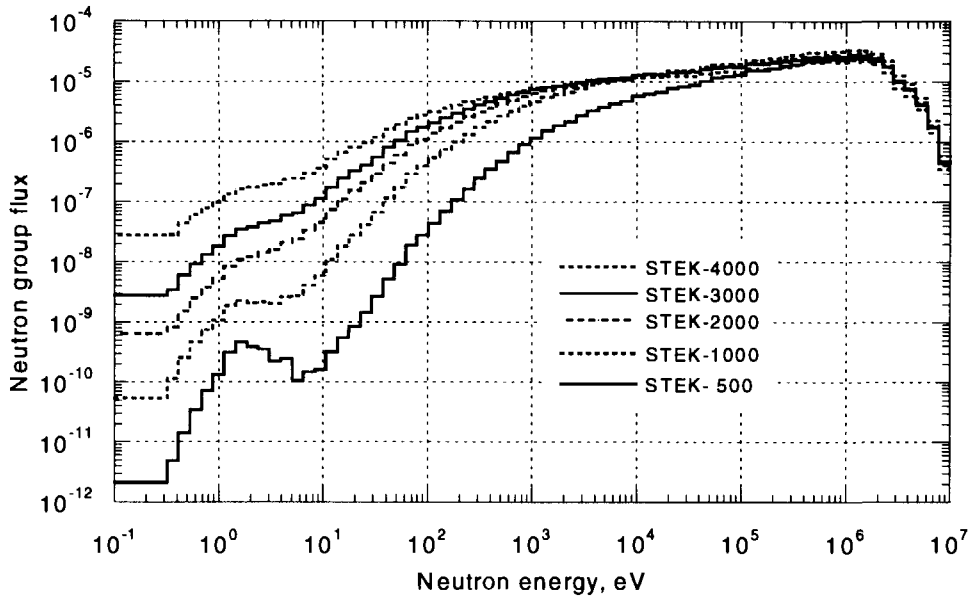

Fig. 2 : Neutron fluxes at the central position of 5 STEK facilities

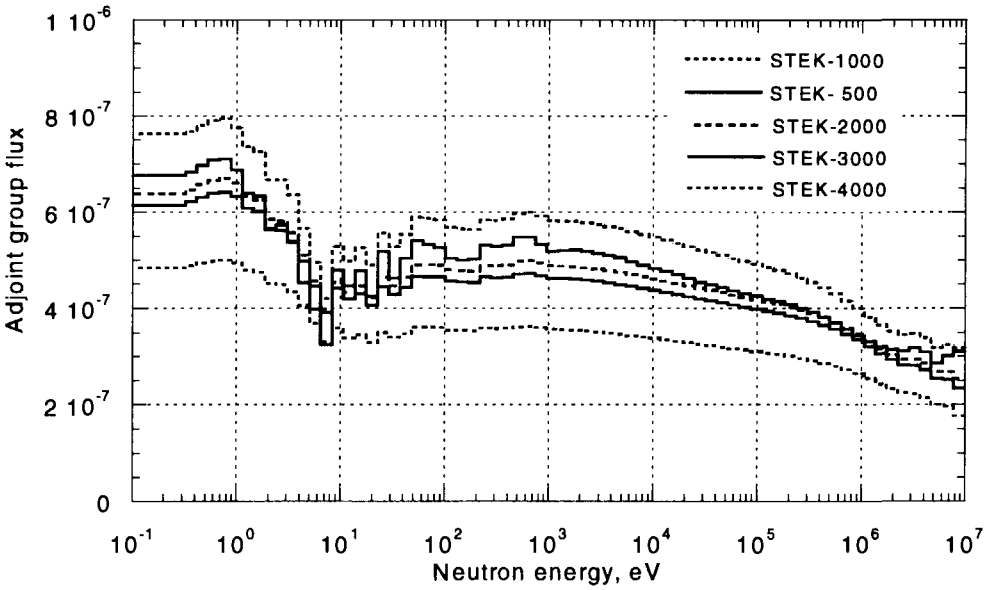

Fig. 3 : Adjoint fluxes at the central position of 5 STEK facilities

Table 1 :
C/E-values of the infinitely dilute sample reactivity of materials under investigation in STEK facilities obtained with the JNC route JENDL-3.2 // SLAROM / CITATION / PERKY. The C/E-values are normalized to the C/E-value of boron-10. The 22 most important FP nuclides for fast reactor calculation are marked. The errors are estimated and based on the experimental (statistical) errors [10] and an additional error due to the normalization.

- no measurement (or CRW) was found in reports.

x measured reactivity or the infinitely dilute values are very small or near zero

! Discrepancies are highlighted (? – questionable)

MAT	STEK-4000	STEK-3000	STEK-2000	STEK-1000	STEK-500	Comment
B-10	1.00 ± 4%	1.00 ± 5%	1.00 ± 4%	1.00 ± 4%	1.00 ± 4%	Normalization
H	1.01 ± 7%	0.96 ± 6%	0.97 ± 6%	1.00 ± 5%	0.98 ± 6%	Standard
C	1.03 ± 5%	0.93 ± 6%	0.94 ± 8%	0.96 ± 6%	0.94 ± 6%	Standard
O	0.91 ±20%	0.96 ± 7%	0.93 ± 6%	0.96 ± 5%	1.01 ± 6%	
Al	1.05 ± 6%	0.97 ± 8%	0.99 ± 8%	1.06 ± 5%	1.07 ± 7%	
Si	**0.87 ± 6%**	**0.77 ±13%**	**0.78 ±12%**	**0.84 ± 6%**	-	**!**
Cl	1.09 ± 9%	1.13 ± 9%	1.32 ±12%	1.53 ±13%	1.11 ±14%	
V	x	**0.54 ± 8%**	**0.59 ± 8%**	**0.73 ± 8%**	-	**Small effect, !**
Cr	x	**0.41 ± 7%**	**0.47 ± 9%**	**0.56 ± 8%**	-	**Small effect, !**
Fe	x	**0.38 ±10%**	**0.50 ± 8%**	**0.70 ± 7%**	**0.86 ± 6%**	**Small effect, !**
Zr-90	**0.58 ±29%**	**0.78 ±28%**	**0.71 ±28%**	**0.75 ±24%**	**0.89 ±21%**	**Small effect, !**
Zr-91	**1.51 ±13%**	**1.37±15%**	**1.43 ±15%**	**1.22 ±22%**	**1.24 ±68%**	**!**
Zr-93	**0.32 ±43%**	**0.40 ±59%**	**0.37 ±54%**	**0.28 ±57%**	**0.35 ±44%**	**!**
Zr-96	2.20 ±28%	x	2.36 ±79%	1.13 ±63%	0.86 ±29%	Small effect
Nb	1.05 ± 8%	1.06 ±10%	1.08± 9%	1.06 ± 7%	1.01 ± 6%	Absorber
Mo	1.02 ± 8%	0.98 ± 9%	1.04 ±12%	0.99 ±10%	0.98 ±11%	Absorber
Mo-92	1.08 ±48%	1.01 ±61%	0.97 ±54%	0.66 ±53%	x	
Mo-94	x	0.66 ±49%	0.85 ±37%	1.62 ±70%	0.37 ±60%	Small effect
Mo-95	0.80 ±12%	0.81 ±14%	0.87 ±14%	0.88 ±13%	0.82 ±16%	Important FP, ?
Mo-96	1.04 ±36%	0.91 ±57%	0.96 ±50%	1.17 ±51%	x	Small effect
Mo-97	0.77 ±16%	0.79 ±15%	0.93 ±12%	0.97 ± 9%	0.99 ±13%	Important FP
Mo-98	**2.33 ±12%**	**1.69 ±20%**	**2.14 ±23%**	x	x	**Important FP, !**
Mo-100	**1.87 ±15%**	**1.75 ±27%**	x	x	x	**Important FP, !**
Tc-99	**0.84 ±11%**	**0.66 ±12%**	**0.69 ±15%**	**0.72 ±17%**	**0.88 ± 8%**	**Important FP, !**
Ru-101	1.16 ±12%	0.99 ±13%	1.03 ±13%	0.98 ±14%	1.04 ±11%	Important FP
Ru-102	0.67 ±27%	1.05 ±20%	1.10 ±19%	1.43 ±23%	1.95 ±61%	Important FP, ?
Ru-104	1.09 ±38%	1.09 ±32%	1.23 ±39%	1.84 ±36%	1.24 ±38%	Important FP
Rh-103	0.95 ± 8%	0.97 ± 9%	0.93 ± 9%	0.92 ± 7%	0.90 ±11%	Important FP
Pd-104	**1.30 ±45%**	**1.46 ±44%**	**1.55 ±47%**	**1.40 ±52%**	**1.58 ±84%**	**?**
Pd-105	0.88 ±10%	0.85 ±12%	0.96 ±10%	1.03 ± 9%	0.99 ± 9%	Important FP
Pd-106	**1.59 ±16%**	**1.47 ±17%**	**1.44 ±15%**	**1.40 ±19%**	**1.43 ±29%**	**!**
Pd-107	0.93 ± 9%	0.92 ±10%	1.07 ±11%	1.11 ±11%	1.04 ± 9%	Important FP
Pd-108	0.97 ±23%	0.81 ±17%	0.95 ±22%	1.39 ±42%	1.17 ±39%	Important FP
Pd-110	1.05 ±36%	x	0.89 ±86%	0.59 ±40%	x	
Ag-109	**0.78 ±11%**	**0.55 ±13%**	**0.84 ±15%**	**0.72 ±19%**	**0.76 ±14%**	**Important FP, !**
Cd-111	0.95 ±24%	1.10 ±25%	1.07 ±22%	0.89 ±21%	0.95 ±22%	
Te-128	x	x	x	x	**0.54 ±28%**	**Small effect, !**
Te-130	x	x	0.79 ±44%	1.02 ±39%	x	Small effect
I-127	**0.73 ±11%**	**0.82 ±17%**	**0.92 ±14%**	**0.87 ±16%**	**0.81 ±20%**	**?**
I-129	0.86 ±28%	0.88 ±29%	0.93 ±28%	1.08 ±21%	1.12 ±26%	Important FP
Cs-133	**0.65 ±10%**	**0.58 ±13%**	**0.70 ± 9%**	**0.80 ± 8%**	**0.71 ±12%**	**Important FP, !**
Cs-135	x	**0.43 ±70%**	**0.61 ±84%**	**0.71 ±85%**	**0.23 ±84%**	**Large err., ?**
La-139	1.17 ± 8%	1.35 ±55%	x	x	0.81 ±53%	Small effect

continued

Ce-140	1.54 ±64%	0.55 ±54%	0.68 ±39%	0.98 ±24%	0.49 ±45%	Small effect
Ce-142	x	**0.44 ±65%**	**0.27 ±25%**	**0.36 ±19%**	**0.33 ±17%**	**!**
Pr-141	0.99 ±19%	1.06 ±25%	0.87 ±21%	1.49 ±29%	0.80 ±38%	Important FP
Nd-142	x	0.76 ±69%	0.98 ±47%	0.73 ±40%	0.93 ±54%	Small effect
Nd-143	0.66 ±18%	0.84 ±25%	0.86 ±25%	0.99 ±14%	0.88 ±24%	Important FP
Nd-144	0.36 ±37%	0.58 ±45%	0.92 ±54%	0.85 ±44%	x	
Nd-145	0.47 ±25%	0.58 ±28%	0.71 ±22%	0.87 ±18%	0.90 ±22%	Important FP
Nd-146	0.82 ±37%	0.87 ±72%	1.58 ±84%	x	x	Small effect
Nd-148	0.76 ±23%	0.79 ±24%	0.92 ±18%	1.13 ±19%	x	
Nd-150	0.75 ±33%	0.92 ±49%	1.30 ±25%	1.69 ±23%	x	
Pm-147	0.78 ±19%	0.65 ±24%	0.76 ±21%	0.86 ±15%	0.89 ±12%	Important FP
Sm-147	0.86 ±15%	0.87 ±24%	1.11 ±24%	0.95 ±12%	0.96 ±14%	
Sm-148	0.49 ±25%	0.59 ±52%	0.90 ±33%	1.23 ±36%	1.54 ±84%	
Sm-149	1.25 ±14%	0.89 ±15%	0.87 ±14%	0.88 ±13%	1.05 ±10%	Important FP
Sm-150	0.86 ±19%	0.75 ±25%	0.77 ±21%	0.81 ±22%	0.89 ±21%	
Sm-151	**0.46 ±60%**	**0.42 ±54%**	**0.44 ±51%**	**0.50 ±53%**	**0.55 ±55%**	**Important FP, !**
Sm-152	0.80 ±25%	0.69 ±39%	0.75 ±27%	0.78 ±26%	0.92 ±37%	
Sm-154	0.77 ±27%	0.85 ±38%	0.99 ±32%	1.00 ±28%	0.84 ±46%	
Eu-151	0.84 ±14%	0.72 ±17%	0.80 ±16%	0.86 ±12%	0.81 ±17%	From Eu-nat
Eu-153	0.92 ±11%	0.94 ±16%	1.02 ±14%	0.99 ±12%	0.98 ±13%	Important FP
Gd-156	1.69 ±18%	1.89 ±28%	1.43 ±25%	0.98 ±27%	1.17 ±63%	?
Gd-157	3.19 ± 8%	1.41 ±11%	1.24 ±12%	0.99 ±14%	1.23 ±21%	?
Tb-159	0.96 ± 6%	0.92 ±13%	1.01 ± 7%	1.08 ± 8%	1.10 ±12%	
Hf	1.27 ±11%	1.00 ±18%	0.99 ±14%	0.98 ±11%	1.02 ±13%	Absorber
W	0.69 ±13%	-	0.90 ±15%	0.87 ±12%	0.80 ±24%	Absorber, ?
Pb	**1.67 ± 7%**	**1.98 ± 9%**	**1.53 ±13%**	**1.55 ± 7%**	**1.72 ± 6%**	**Small effect, !**
Th-232	**1.64 ± 7%**	-	-	**1.32 ±10%**	-	**!**
U-235	1.09 ± 6%	0.98 ± 7%	0.96 ± 6%	1.00 ± 5%	1.01 ± 5%	Standard
U-236	1.27 ±12%	-	-	0.81 ±29%	-	
U-238	0.87 ±15%	0.90 ±20%	1.11 ±22%	1.41 ±24%	x	
Pu-239	1.13 ± 8%	0.94 ± 8%	0.96 ± 7%	1.01 ± 8%	1.03 ± 7%	
Pu-240	**1.62 ±20%**	**1.65 ±45%**	**1.28 ±53%**	x	-	**Large err., ?**

Table 2 :
C/E-values of SEG-5 normalized to the C/E-value of boron-10. The capture effect is dominant. Very discrepant results are highlighted.

Sample Material	**C/E-values JNC route 70g JENDL-3.2/JNC codes**	**C/E-values Cross-wise use 70g JEF-2.2/JNC codes**	**C/E-values European scheme 33g JEF-2.2/ECCO/ERANOS**	**Error (%)**
B-10 ss	1.000	1.000	1.000	2
Ta	0.956	0.933	0.956	7
U-235	1.138	1.124	1.084	10
Mo	1.031	0.984	0.964	10
Mn	**0.658**	0.942	0.952	7
Cd	1.070	**1.214**	**1.215**	9
Nb	1.072	1.048	1.022	9
Cu	1.174	1.214	1.119	14
Zr	**1.302**	1.085	1.032	13
W	0.918	1.019	1.085	8
Fe	**1.342**	**1.232**	1.084	11
Cr	1.037	1.095	1.032	10
Ni	**1.237**	**1.185**	1.073	10
Co	1.032	1.076	0.992	10

continued

B-10 fp	1.000	1.000	1.000	2
Mo-95	**1.185**	**1.194**	**1.133**	10
Mo-97	0.980	0.994	0.954	10
Mo-98	1.035	1.039	1.061	15
Mo-100	0.996	0.923	0.888	16
Rh-103	0.899	0.914	0.901	7
Pd-105	1.117	1.077	1.064	7
Ag-109	**0.886**	0.926	0.929	8
Cs-133	0.909	0.912	0.926	13
Nd-143	0.882	0.897	0.896	9
Nd-145	1.020	1.018	1.066	9
Sm-149	1.023	**1.121**	**1.191**	9
Eu-153	1.059	1.068	1.091	10

Table 3 :
C/E-values of SEG-6/45 normalized to the C/E-value of hydrogen or carbon. The scattering effect is dominant. Very discrepant results are highlighted.

Sample Material	**C/E-values JNC route 70g JENDL-3.2/JNC codes**	**C/E-values Cross-wise 70g JEF-2.2/JNC codes**	**C/E-values European scheme 33g JEF-2.2/ECCO/ERANOS**	**Error (%)**
H	1.000	1.000	1.071	5
C	0.918	0.959	1.000	8
B-10	0.823	0.821	0.896	12
Mo	0.935	0.898	0.913	7
Fe	0.925	0.952	0.916	7
Cr	0.887	0.977	0.915	7
Ni	0.986	1.096	1.133	9
Al	1.109	1.202	1.032	8
Zr	0.918	**0.859**	**0.860**	8
Ti	0.911	0.881	0.921	8
Cd	**0.802**	1.026	1.105	7
Pb	**1.166**	0.883	0.913	12
Bi	0.911	0.986	1.016	12
Mg	1.082	1.014	1.094	13
Be	**1.186**	**1.138**	**1.323**	7
W	0.926	0.912	0.942	9
Cu	1.046	1.063	1.095	8
Au		0.919	0.963	9
Mn	0.896	1.045	1.076	8
Ta	0.874	0.834	0.895	7
V	0.934	1.034	1.016	9
Si	0.893	1.049	**1.207**	11
Nb	0.943	0.900	0.955	8
Co	1.119	**1.184**	**1.241**	8
U-235	0.898	0.907	0.978	7
U-238	0.906	0.881	0.923	12
Th-232	0.858	0.832	0.865	9