Research Centre Rez, Czech Republic

Comparison of Two Independent Neutron Spectrometry Methods, Proton-Recoil and Time-of-Flight, used for Iron Nuclear Data Libraries validation. TENDL 2015 - Iron data validation.

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Motivation

Using the experimental method, we try to validate the nuclear data library that is used in the parallel calculation. (We assume at this point that the computation code is correct).

But is this used experimental method correct and how accurate is it? Everyone who measures something has to ask this question from time to time.

In this paper, we are attempting to compare the results of two completely different methods of measuring neutron spectra.

1) **TOF (time of flight), where** the neutron energy is determined by measuring the time at which the neutron travels the given constant distance from the point of origin to the detector.

2) **PR (Proton recoil)** method, where we measure the spectrum of recoiled charged particles - protons using a hydrogen proportional detector-HPD (En<1MeV, approx.) or a scintillator – stilbene for recoil proton spectrum measurement (En>1MeV) .

Abstract

A) The measurements (M) of leakage neutron spectra from the iron spherical assemblies of approximately the same diameters (50 resp. 60cm for PR resp TOF) have been done by two independent methods. The neutron source was always positioned in the center of iron spheres.

1) In the first case an encapsulated Cf-252 neutron source and proton recoil (PR) method for neutron spectrum measurement were used (hydrogen proportional counters and stilbene).

2) In the second case neutron spectrum was measured by the Time-of-Flight(TOF) method.

Two versions of neutron source were used for TOF method

2a) pulsed 14 MeV source

2b) thin Cf-252 fission chamber

The neutron spectra leaking from these assemblies were calculated (C) in both cases with the same data library, as well as the ratios C/M in the proper wide neutron energy groups.

Abstract-continued

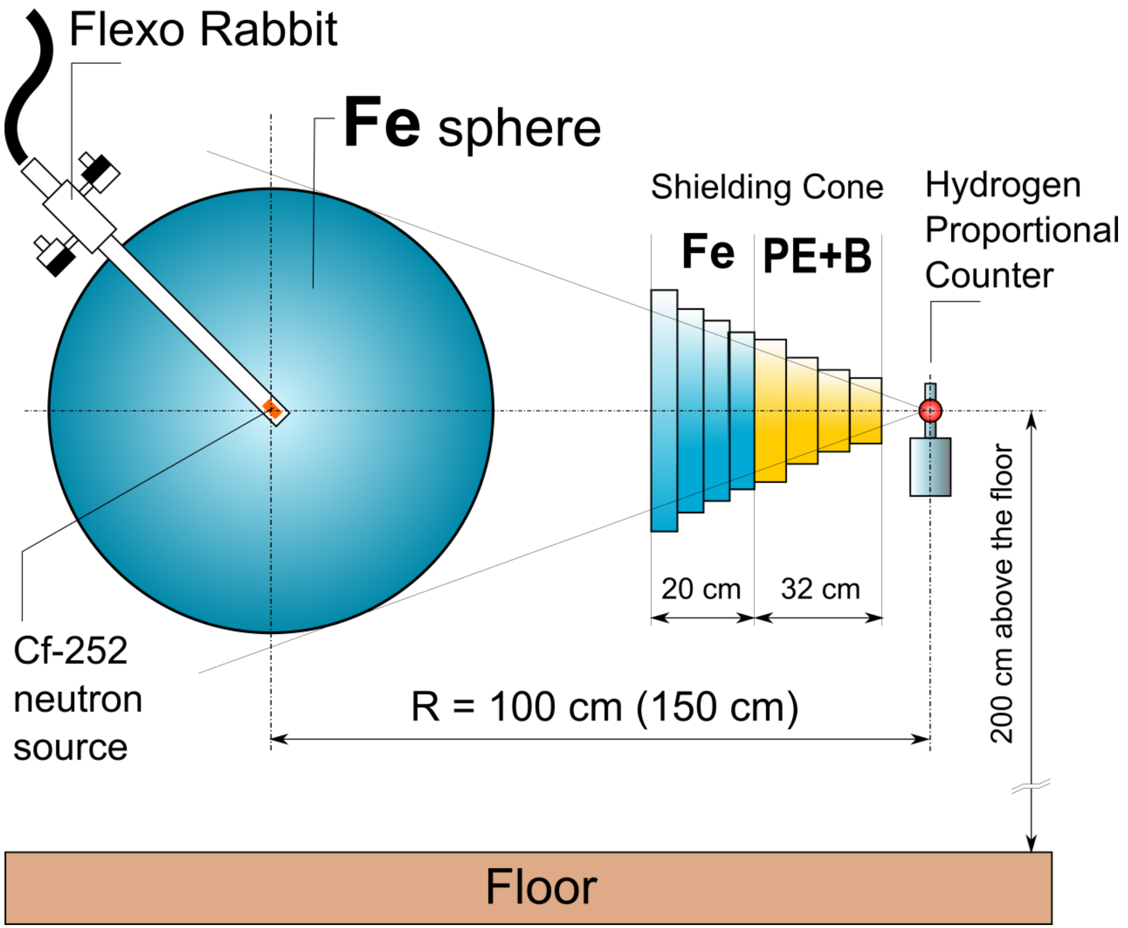
Finally these quantities obtained from the two independent measurements PR and TOF were compared to derive conclusion about the validity of the neutron transport library.

B) TENDL-2015, Iron neutron data validation , spherical Fe assembly, Cf source in centre

Experimental assembly for proton recoil measurements

Fig. 1 Benchmark assemblies

The spherical shape of assemblies (Fe, Ni, H_2O,D_2O,…) and spherical neutron source is used for calculation because this geometry represents the simplest one-dimensional (1D) task. As a matter of fact, the assembly is a 3D object.



Methodology of calculation and measurement

Measurement effect evaluation

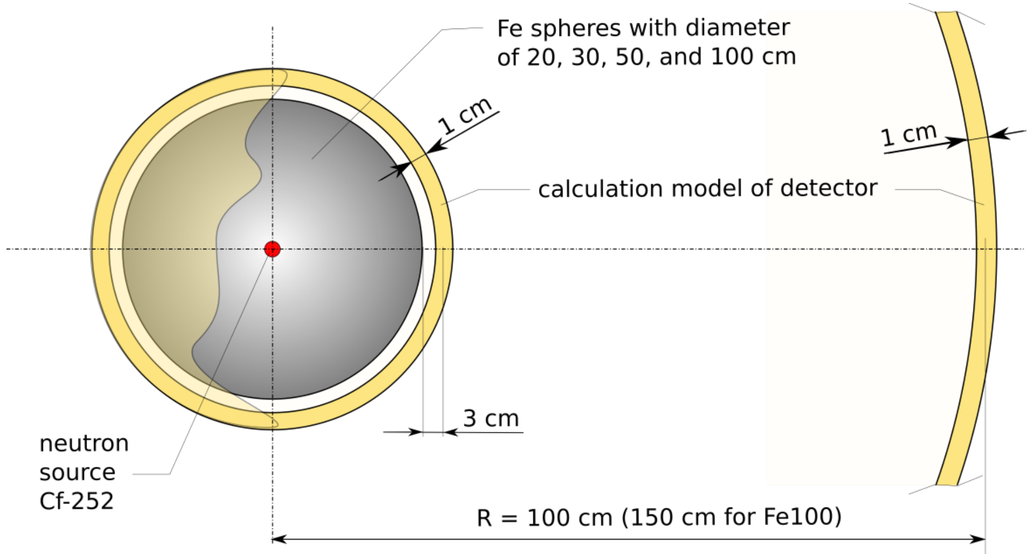
- The background of the measured field is determined by additional measurement performed with shielding cone has to shield corresponding space angle to measure all unwelcome scattered neutrons and laboratory background neutrons. The background effect is subtracted.

- Energy scale is 40 or 200 groups per decade (gpd) for HPD and constant energy step for stilbene.

.Fig.2 PR- Methodology of calculation and measurement

Calculations

The calculations were performed using Monte-Carlo program MCNP. As for geometry description, a simplified model was used, which substitutes assembly elements with concentric spherical shells around the source. Also, the detector is represented by a **1 cm** thick spherical shell with radius equal to the real detector-source distance (R=28 and 100 cm).



The energy bin structure of resulting tallies was chosen to be logarithmic, either with 40 or with 200 groups per decade. Contemporary the energy scale with constant energy step (0.1MeV) is used in calculation for using in C/E for stilbene.

Methodology of calculation and PR measurement

Normalization of results

The result of spectra calculation and measurement φ(E) [$cm^{-2}s^{-1}MeV^{-1}$] is normalized in the following way:

$$\varphi(E)\ 4\pi \cdot R^2 / Q, \quad [1/\text{MeV}] \qquad (1)$$

where R is distance between detector and neutron source (centre to centre)

and Q [1/s] is neutron source emission.

Quantity depicted in the figures has the following form and dimension

$$E 4\pi R^2 \varphi(E) / Q \quad [1] \qquad (2)$$

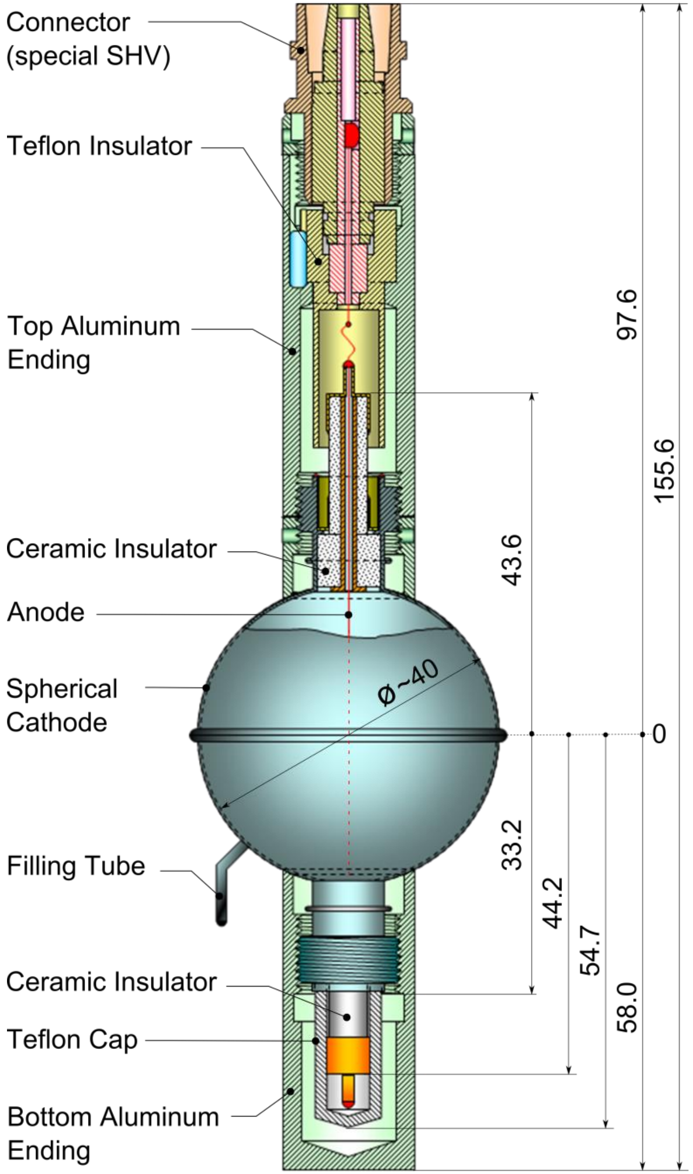
The integral values presented in following tables are also with dimension of 1.

The measured and calculated spectra were evaluated in two group structures: 40 gpd (group per decade), it corresponds to the lethargy step about 6% and in structure 200 gpd, i.e., with lethargy step about 1%. Structure 200 gpd is proper only for measurements with very good statistics, but it represents long exposure time. The calculated spectra were usually smoothed by Gaussian with constant percentage resolution Δ of FWHM: Δ=13% for 40 gpd and Δ=4% for 200 gpd. The aim of this smoothing is to obtain the form of calculated spectrum similar to measured spectrum with detector of given resolution.

PR neutron spectrometry- HPD

Tab.A. Detectors used with neutron spectrometers

Detector type	Type	Pressure	Dimension	Energy range [MeV]
Proportional Counter filled by Hydrogen (HPD)	NOK145 NOK445 NOK1045	100 kPa 400 kPa 1000 kPa	Ø 40 mm	0.01-0.3 0.2-0.8 0.5-1.3



Proton recoil neutron spectrometry

- The **proton recoil method** was used for neutron spectra measurement using
  - a)HPD, spherical hydrogen proportional detectors
  - b) stilbene
- **HPD-**Neutron energy range of spectrometer is **from 0.1 to 1.3 MeV**. This energy interval represents about **85 % of all leakage neutrons** from Fe sphere of diameter 50 cm and about of 74% for Fe sphere of diameter 100 cm. The neutron **energy structure** used for calculations and measurements was **40 gpd and 200 gpd**. Structure 200 gpd represents lethargy step about of 1%. This relatively fine energy structure enables to analyze the **Fe resonance neutron energy structure.** Program SPED (written in RC Rez) is used for neutron aparatus spectra evaluation. Program GRUP (written in RC Rez) is used for calculation and measurement results analyse.
- **Stilbene** - Neutron energy range of spectrometer is **from 1 to 17 MeV**. In this report are included the experimental results obtained by **stilbene neutron spectrometer**. The neutron and gamma spectra were measured and evaluated in NRI Rez (now RC Rez) by Dr. Lev A.Trykov (+2009) from FEI Obninsk (1990-2009 approx). The stilbene energy structure has constant energy step in various energy regions.

TOF - pulsed 14 MeV source (Simakov, IPPE Obninsk)

Objective :

Re-analysis of neutron leakage spectra from

IPPE Iron spheres feed by d-T (14 MeV) source

[Numerical Data and Details of Experiment and Simulation:
- SINBAD Fusion NEA-1553/75 http://www.oecd-nea.org/tools/abstract/detail/nea-1553
- S.P.Simakov, B.V.Devkin et al., EFF-DOC-747, NEA 2000]

Motivations:

- New Evaluations for Fe istopes in frame of CIELO
- Discrepancies (C/E .ne. 1) observed by B.Jansky et al.
  for ^{252}Cf driven Iron spheres
  presented and discussed at ND-2016 in September

Results: whole Energy Range: 14 MeV down to threshold

Present: one thickest Fe shell #5
- outer/inner R/r = 30/2 cm
- source: pulsed 14 MeV
- method: Time of Flight
- detector: Stilbene

C/E from Jansky: two Fe shells
- outer R = 50 and 25 cm
- source: ^{252}Cf
- method: Pulse Height
- detector: Hydrogen Proportional Counter
- reference: B.Jansky et al., ND2016, R152

Observations:
- CIELO shows better performance cp. ENDF/V-VII.1 in interval 5 - 10 MeV
- C/E derived from two independent experiments (even with different sources) show agreement in interval 0.2 – 1.3 MeV

TOF with Cf-252 fission chamber, (Simakov, IPPE Obninsk)

IPPE Iron Sphere Neutron Leakage Experiment with pulsed ^{252}Cf(s.f.) source

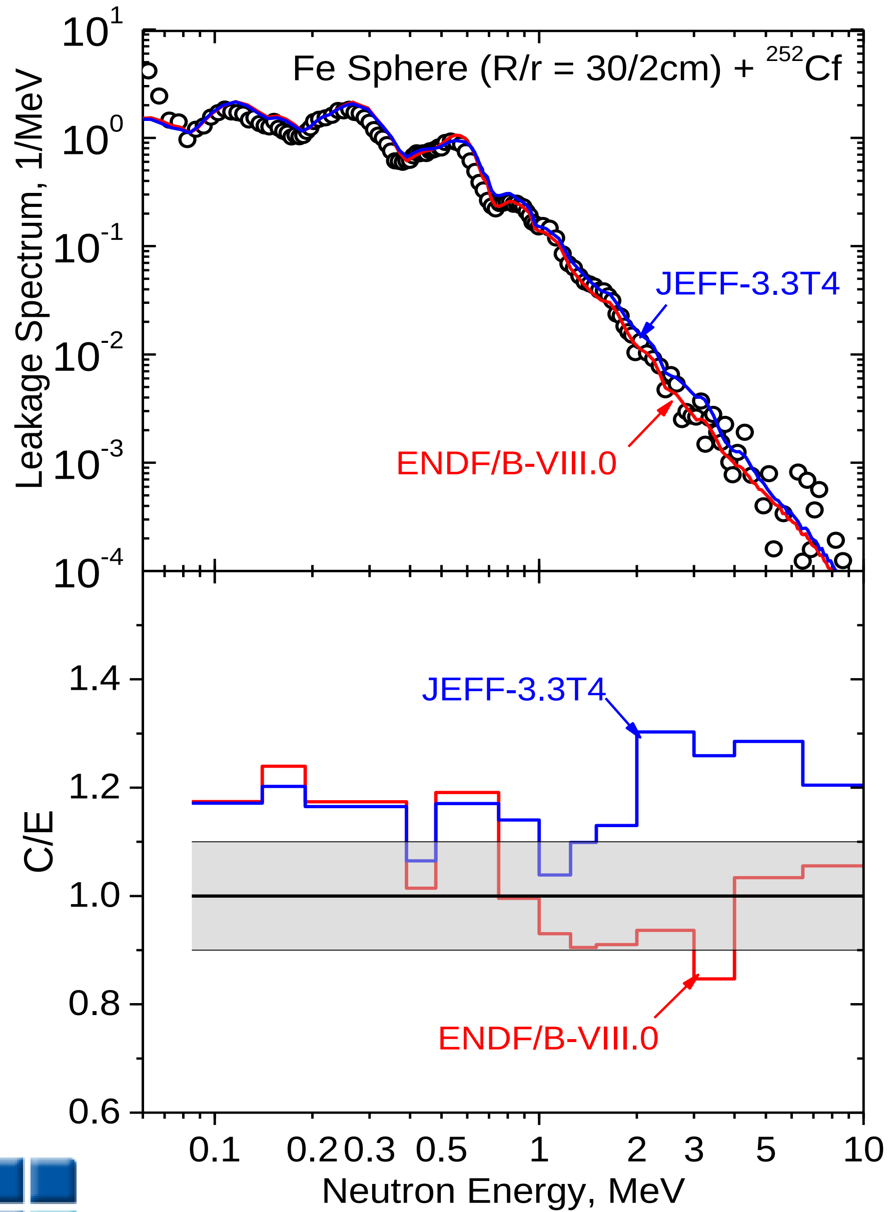
Fe sphere: **R/r = 30/2 cm , Wall thickness = 28 cm**

Neutron Source: **thin ^{252}Cf fission chamber, intensity ≈ 1.E+6 n/s**
(fast Fission signal was used as a Stop for TOF)

Neutron detection: TOF, Scintillation Detector p-Terphenil at Flight Path ≈ 5 m,
n-Threshold ≈ 50 keV (fast PM signal - Start for TOF)

Reference: *S.Simakov et al., VANT Yadernye Konstanty 3-4(1992)93;*
Report INDC(CCP)-351, 1993, Vienna

Results for IPPE Fe sphere R/r=30/2cm with Cf(s.f.) pulsed source



MCNP simulation details:

- Cf(s.f.) n-spectrum = standard (Mannhart)
- latest transport libraries for all Fe istopes from JEFF-3.3T4 and ENDF/B-VIII.0
- full modelling of experimental set-up including first TOF then conversion in Energy Spectrum

TAB 1, Comparison HPD(C/E) and TOF-14MeV(C/E), E<1.3 MeV
(HPD=hydrogen proportional detector)

	HPD/TOF , JEFF-3.3T2 and JEFF-4.0T0, En<1.3 MeV								
	dE HPD>	E[MeV]	0.1-0.15	0.15-0.2	0.2-0.41	0.41-0.51	0.51-0.75	0.75-1.0	1.0-1.3
JEFF-3.3T2	C/E HPD		1,041	1,047	1,096	1,193	1,066	1,184	0,974
	C/E TOF	Simakov data>	1,1747	1,0936	1,1453	1,1246	1,1012	1,1553	0,99965
	A-HPD/TOF		0,8859	0,9571	0,9573	1,0606	0,9677	1,0249	0,9745
JEFF-4.0T0	C/E HPD		1,1164	1,1397	1,1343	1,1477	1,0778	1,0286	0,7746
	C/E TOF	Simakov data>	1,237	1,210	1,202	1,091	1,119	1,009	0,816
	B-HPD/TOF		0,902	0,942	0,943	1,052	0,963	1,020	0,949
JF-3/JF-4	A/B ratio		0,9817	1,0161	1,0146	1,0082	1,0045	1,0052	1,0271
	good,d<5%		E=EXP						
	good,d<3%		C=CALC						

TAB 2 , Comparison stilbene(C/E) and TOF-14MeV(C/E), E>1MeV

	STL/TOF , JEFF-3.3T2 and JEFF-4.0T0, En>1MeV									
	dE STL>	E[MeV]	1-1.25	1.25-1.5	1.5-2	2-3	3-4	4-6.5	6.5-10.5	10.5-18
JEFF-3.3T2	C/E STL		0,970	0,876	1,032	1,168	1,260	1,201	1,157	0,850
	C/E TOF	Simakov data>	0,99965	1,0771	1,0971	1,1500	1,2124	1,1563	1,1173	1,0144
	A-STL/TOF		0,9707	0,8135	0,9404	1,0160	1,0389	1,0388	1,0354	0,8379
JEFF-4.0T0	C/E STL		0,7619	0,7760	0,9230	0,9228	0,8562	0,9658	1,0241	0,8046
	C/E TOF	Simakov data>	0,8164	0,9788	0,9809	0,9240	0,8926	0,9948	0,9809	0,9967
	B-STL/TOF		0,9332	0,7929	0,9410	0,9988	0,9592	0,9708	1,0441	0,8073
JF-3/JF-4	A/B ratio		1,040	1,026	0,999	1,017	1,083	1,070	0,992	1,038
	good,d<5%		E=EXP							
	good,d<3%		C=CALC							

TAB 3, Comparison HPD(C/E) and TOF-Cf (C/E), E<1.3 MeV
(HPD=hydrogen proportional detector)

	HPD/TOF , JEFF-3.3T4 and JEFF-4.0T0, En<1,3MeV								
	dE HPD>	E[MeV]	0.1-0.15	0.15-0.2	0.2-0.41	0.41-0.51	0.51-0.75	0.75-1.0	1.0-1.3
JEFF-3.3T4	C/E HPD		1,041	1,049	1,094	1,196	1,071	1,184	0,957
	C/E TOF	Simakov data>	1,171	1,202	1,165	1,065	1,171	1,140	1,039
	A-HPD/TOF		0,8888	0,8723	0,9391	1,1236	0,9148	1,0387	0,9210
JEFF-4.0T0	C/E HPD		1,1164	1,1397	1,1343	1,1477	1,0778	1,0286	0,7746
	C/E TOF	Simakov data>	1,086	1,203	1,219	1,047	1,229	0,993	0,846
	B-HPD/TOF		1,028	0,947	0,931	1,096	0,877	1,036	0,916
JF-3/JF-4	A/B ratio		0,8646	0,9211	1,0088	1,0250	1,0431	1,0029	1,0056
	good,d<5%		E=EXP						
	good,d<5%		C=CALC						

TAB 4 , Comparison stilbene(C/E) and TOF-Cf (C/E), E>1MeV

	STL/TOF , JEFF-3.3T4 and JEFF-4.0T0, En>1MeV								
	dE STL>	E[MeV]	1-1.25	1.25-1.5	1.5-2	2-3	3-4	4-6.5	6.5-10.5
JEFF-3.3T4	C/E STL		0,951	0,884	1,057	1,182	1,264	1,196	1,167
	C/E TOF	Simakov data>	1,039	1,099	1,130	1,303	1,259	1,285	1,205
	A-STL/TOF		0,9150	0,8049	0,9351	0,9071	1,0041	0,9304	0,9690
JEFF-4.0T0	C/E STL		0,7619	0,7760	0,9230	0,9228	0,8562	0,9658	1,0241
	C/E TOF	Simakov data>	0,846	1,015	1,016	1,003	0,845	1,031	1,052
	B-STL/TOF		0,9009	0,7644	0,9086	0,9198	1,0134	0,9368	0,9735
JF-3/JF-4	A/B ratio		1,016	1,053	1,029	0,986	0,991	0,993	0,995
	good,d<5%								
	good,d<5%								

Discussion

1) Tab. 1-2 indicates that ratio PR/TOF(14MeV) is in 79% (22/28) in agreement better than 5% (green columns)
2) Tab. 3-4 indicates that ratio PR/TOF(Cf) is in 29% (8/28) in agreement better than 5% (green columns)
3) Tab. 1-4 indicates that results PR/TOF (14 MeV and Cf) are reproduced very good in given energy group, independent of the fact which Data library is used (red columns). The differences in a lot of energy groups is on the value 1-2%. (red columns)
4) Tab. 1-4 indicates that agreement PR/TOF is much better for TOF(14 MeV) source than for TOF(Cf). One of possible reason is perhaps the low statistics in the case TOF(Cf).
5) It is necessary to take in account that the spherical assemblies for TOF and PR (diameter 50cm for PR and 60 cm for TOF) are not identical and also neutron sources Cf and 14 MeV beam are not identical. the The little energy shift in TOF energy scale was taken into account. Newertheles the agreement between PR and TOF (14 MeV is good (80% on the level 5%)

This comparison increases the credibility of both experimental methods.

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TENDL- 2015, Iron neutron data validation

Proton recoil method was used for TENDL 2015, Iron data validation.

Leakage neutron spectrum from Iron sphere was measured by HPD and stilbene and calculated using TENDL 2015 data library,

Assembly: FE DIA 100, R150 (Fe sphere of diameter 100cm, at distance 150cm from centre)

Source: Cf-252 in centre of sphere, see Fig.1

Fig.3 Neutron spectrum measured by HPD (thick), calculation TENDL- 2015, A.Blokhin, (thin), 200gpd

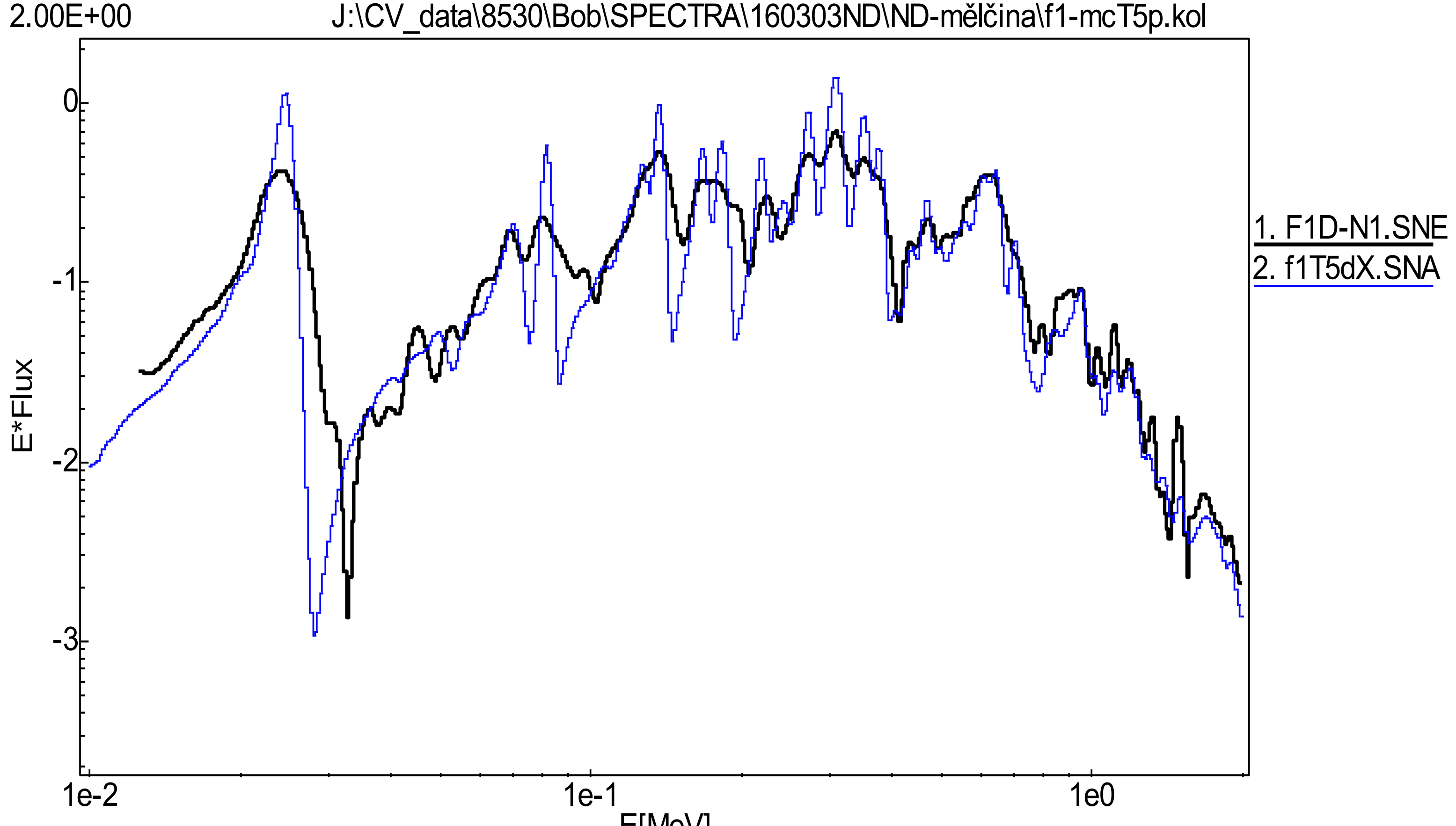

Fig. Assembly FE DIA100. R150. n-spectrum,
Measurement HPD(thick), calc. TENDL-2015 (Blokhin), (thin)

Fig.4 Neutron spectrum measured by stilbene, L.Trykov (thick), calculation TENDL- 2015, A.Blokhin (thin),

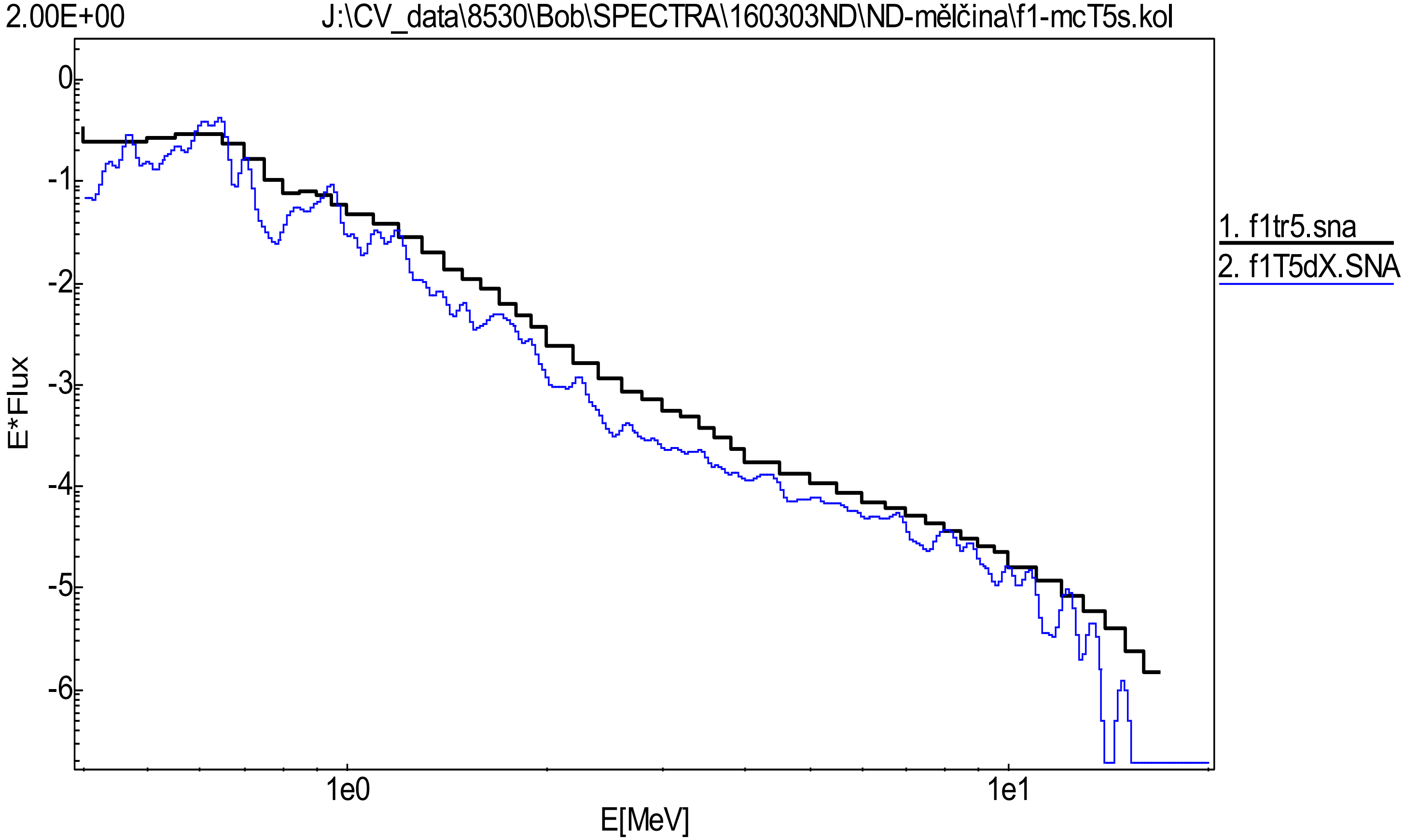

Fig. Assembly FE DIA100. R150. n-spectrum,
Measurement stilbene-Trykov(thick), calc. TENDL-2015 (Blokhin), (thin)

Tab.5 Neutron spectrum measured by HPD, 200gpd calculation by TENDL- 2015, A.Blokhin, (integral values)

Energy range[MeV]		FE DIAM 100cm-Integral values [1]					
		measurements		calculation			
from	to	HPD	U[%]	TENDL-2015	U[%]	CALC/EXP	U[%]
0,01	1,29	8,25E-01	3,27	8,70E-01	0,05	1,06E+00	3,27
0,01	0,03	1,22E-01	9,43	1,40E-01	0,08	1,14E+00	9,43
0,03	0,06	2,07E-02	42,50	2,17E-02	0,21	1,04E+00	42,51
0,06	0,09	6,35E-02	14,29	6,27E-02	0,24	9,88E-01	14,29
0,09	0,15	1,23E-01	9,18	1,19E-01	0,14	9,67E-01	9,18
0,15	0,20	8,35E-02	10,55	7,96E-02	0,16	9,54E-01	10,56
0,20	0,25	4,65E-02	17,46	5,45E-02	0,18	1,17E+00	17,46
0,25	0,29	6,25E-02	9,70	6,82E-02	0,17	1,09E+00	9,70
0,29	0,33	7,18E-02	7,04	1,02E-01	0,14	1,42E+00	7,04
0,33	0,40	7,19E-02	7,40	8,36E-02	0,15	1,16E+00	7,41
0,40	0,52	4,11E-02	12,30	3,88E-02	0,18	9,45E-01	12,30
0,52	0,78	9,25E-02	6,73	8,06E-02	0,12	8,72E-01	6,73
0,78	1,06	1,90E-02	13,84	1,51E-02	0,28	7,96E-01	13,84
1,06	1,29	6,10E-03	13,56	4,76E-03	0,50	7,79E-01	13,57

(green)	0,9<C/E<1.1
(red)	C/E>1.1
(blue)	C/E<0,9

Tab.6 Neutron spectrum measured by stilbene (Trykov) calculation by TENDL- 2015, A.Blokhin, (integral values)

Energy range[MeV]		Fe assemblies				Fe assemblies	
from	to	f1tr5	U[%]	f1T5dX	U[%]	CALC/EXP	U[%]
1,00	17,00	1,49E-02	2,91	8,76E-03	0,38	5,87E-01	2,93
1,00	2,00	1,42E-02	3,05	8,40E-03	0,39	5,93E-01	3,08
2,00	3,00	5,66E-04	4,53	2,46E-04	2,10	4,35E-01	4,99
3,00	5,00	1,47E-04	4,46	7,60E-05	3,63	5,17E-01	5,75
5,00	7,00	2,70E-05	7,13	1,97E-05	7,03	7,28E-01	10,01
7,00	10,00	1,27E-05	6,56	8,76E-06	10,61	6,91E-01	12,47
10,00	17,00	4,09E-06	7,30	2,37E-06	16,51	5,80E-01	18,05

(highlighted) C/E<0,9

Discussion to TENDL 2015 Iron data

1) The biggest Iron sphere was used for iron data validation, because of the C/E differences are usually the biggest

2) Tab.5 indicate not too bad agreement below 1.3 MeV except the peak arround 309keV which is overestimated by 40%

3) Tab. 6 indicate that region En>1 MeV is underestimated by 30-60%

4) It can be assumed that for smaller iron thicknesses the difference will not be so dramatic.

7. References

[1] M.B.Chadwick, CIELO: *A Future Collaborative International Evaluated Library*, conference Nuclear Data , ND 2013, New York, 2013.

[2] B.Jansky, E.Novak, *Neutron Spectrometry with Spherical Hydrogen Proportional Detectors,* Nuclear Instruments and Methods in Physics Research, A735(2014), 390–398.

[3] B. Jansky1,*, J. Rejchrt1, E. Novak1, E. Losa1,
A. I. Blokhin2, and E. Mitenkova2, *Neutron Spectra Measurement and Calculations using Data Libraries CIELO, JEFF-3.2 and ENDF/B-VII.1 in Iron Benchmark Assemblies,* Conference Neutron Data 2016, Brooges, Belgium ,2016

View of the Laboratory for Neutron and Gamma Spectrometry

Benchmark assemblies

KONEC