Status of the Evaluation of the Neutron Spectrum of ^{252}Cf(sf)

Wolf Mannhart
PTB Braunschweig

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Topics

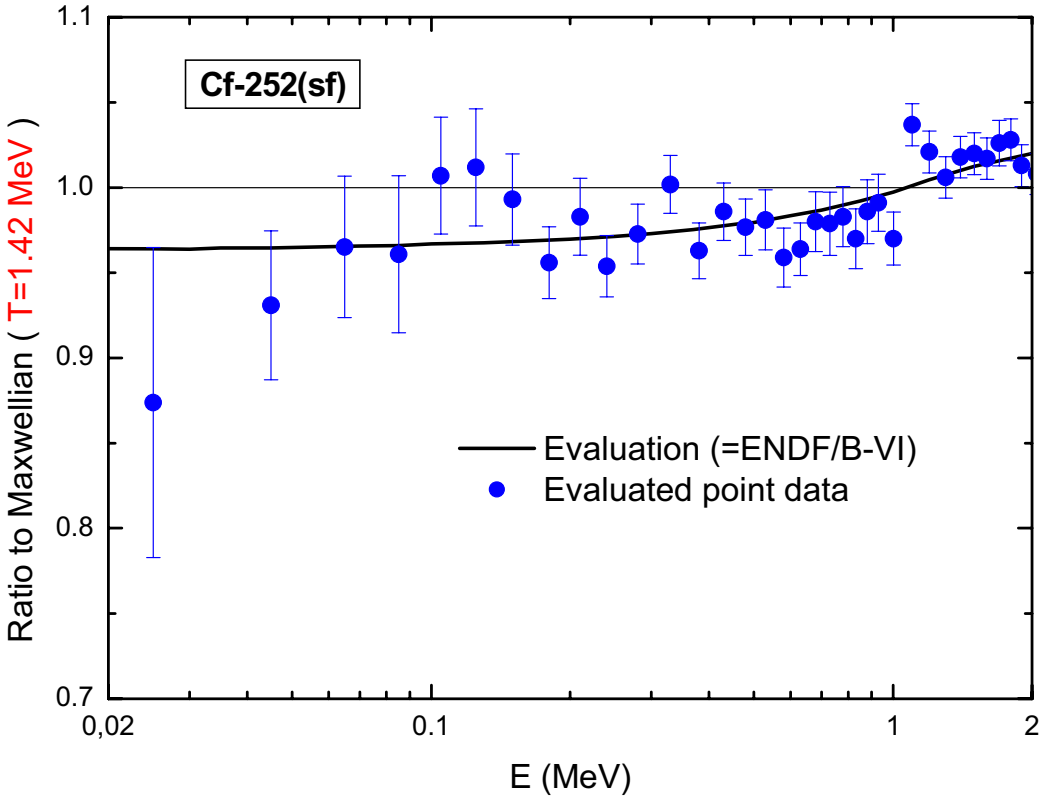
1. **Database and result of the evaluation of 1989**
2. **Recent experiments performed after 1989**
3. **Spectrum-averaged cross sections (integral data)**
   a) **Evaluation of the experimental database**
   b) **Comparison with calculated data**
4. **Summary and conclusions**

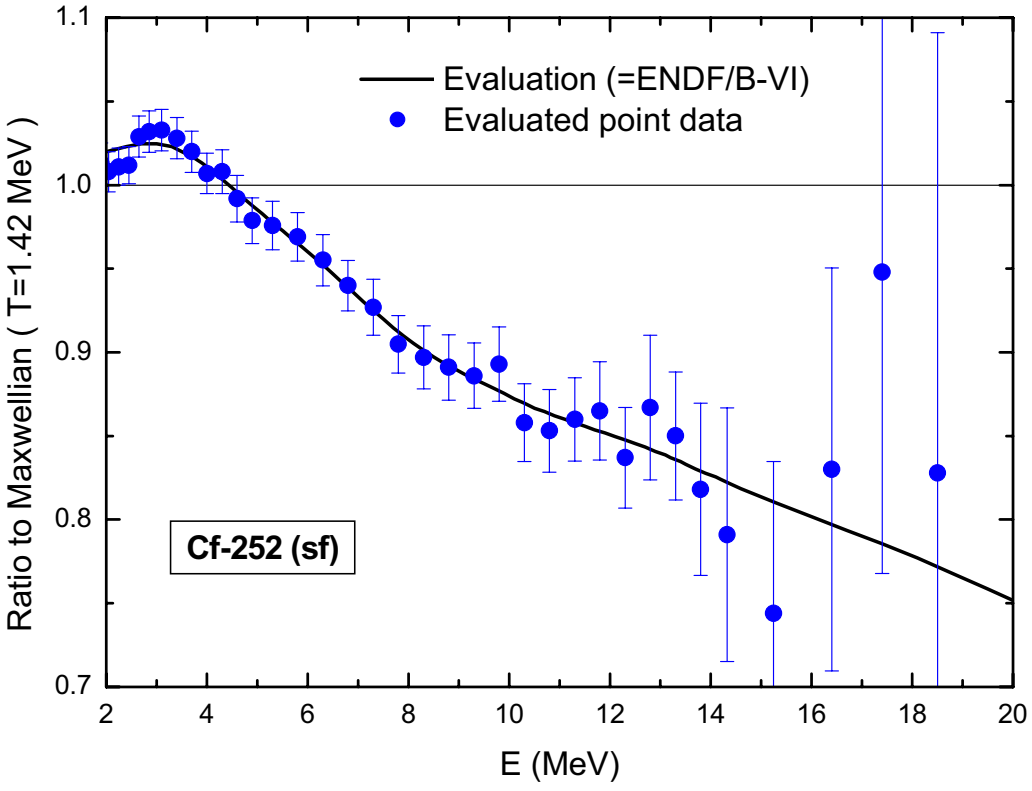
Selection criteria used in the evaluation of 1989

- **Only TOF experiments.**
- **A sufficiently detailed documentation.**
  (needed for the generation of a realistic covariance matrix and to allow the verification of important corrections).
- **Valid corrections for effects which directly influence the shape of the measured spectrum :**
  - **Correction for the background caused by random coincidences (uncorrelated stop events).**
    [see: A. Chalupka, NIM 165 (1979) 103]
  - **Correction for non-isotropic detection losses in the fission fragment detector.**

Experiments used in the 1989 evaluation

Authors	Reference	TOF (m)	Energy range (MeV)
Böttger et al.	NSE 106 (1990) 377	12.00	2.00 - 14.00
Lajtai et al.	Nuclear Data Conf., Mito (1988) p.737	0.30	0.025 – 1.22
Boldeman et al.	NSE 93 (1986) 181	0.40	0.124 – 2.66
		3.02	1.05 – 14.25
Blinov et al.	INDC(CCP)-238 (1985)	0.50	0.042 - 11.36
Märten et al.	INDC(GDR)-28 (1984)	4.50	8.89 – 19.77
Poenitz et al.	Nuclear Data Conf.,. Antwerp (1983) p.465	2.58/ 3.47	0.25 – 9.25


Cf-252(sf)
Evaluation (=ENDF/B-VI)
Evaluated point data
Ratio to Maxwellian (T=1.42 MeV)
E (MeV)
1.1
1.0
0.9
0.8
0.7
0,02
0.1
1
2

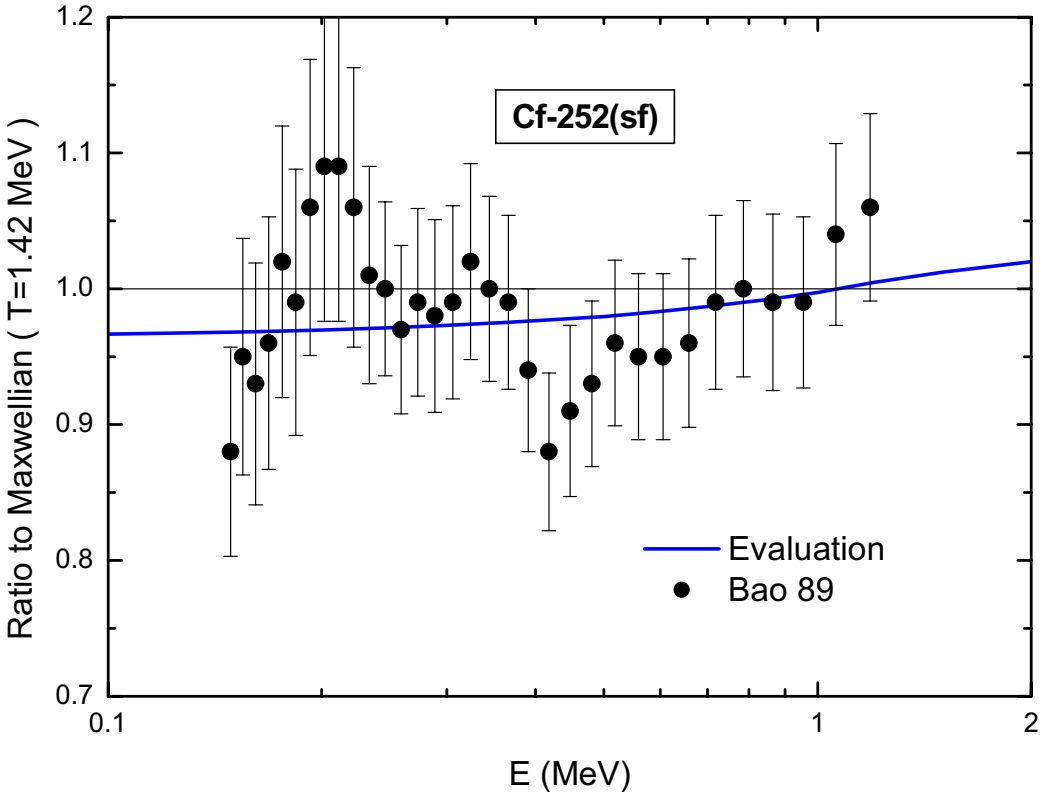

Evaluation (=ENDF/B-VI)
Evaluated point data
Cf-252 (sf)
Ratio to Maxwellian (T=1.42 MeV)
E (MeV)
1.1
1.0
0.9
0.8
0.7
2
4
6
8
10
12
14
16
18
20

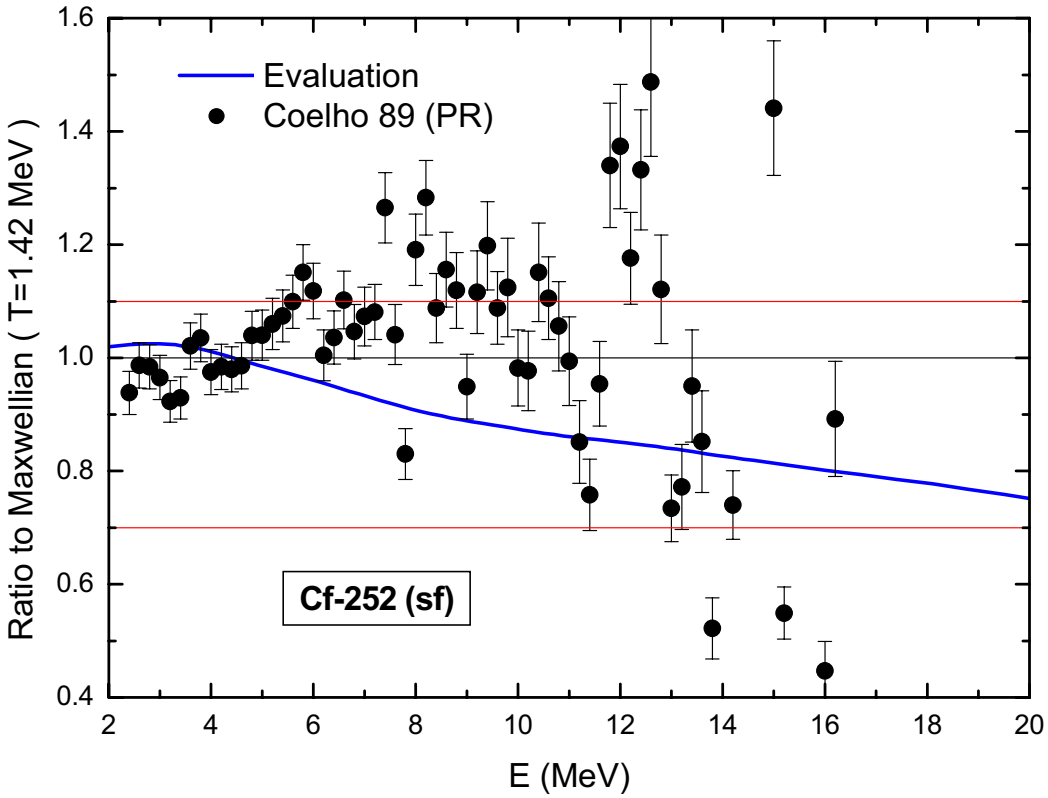
Some remarks

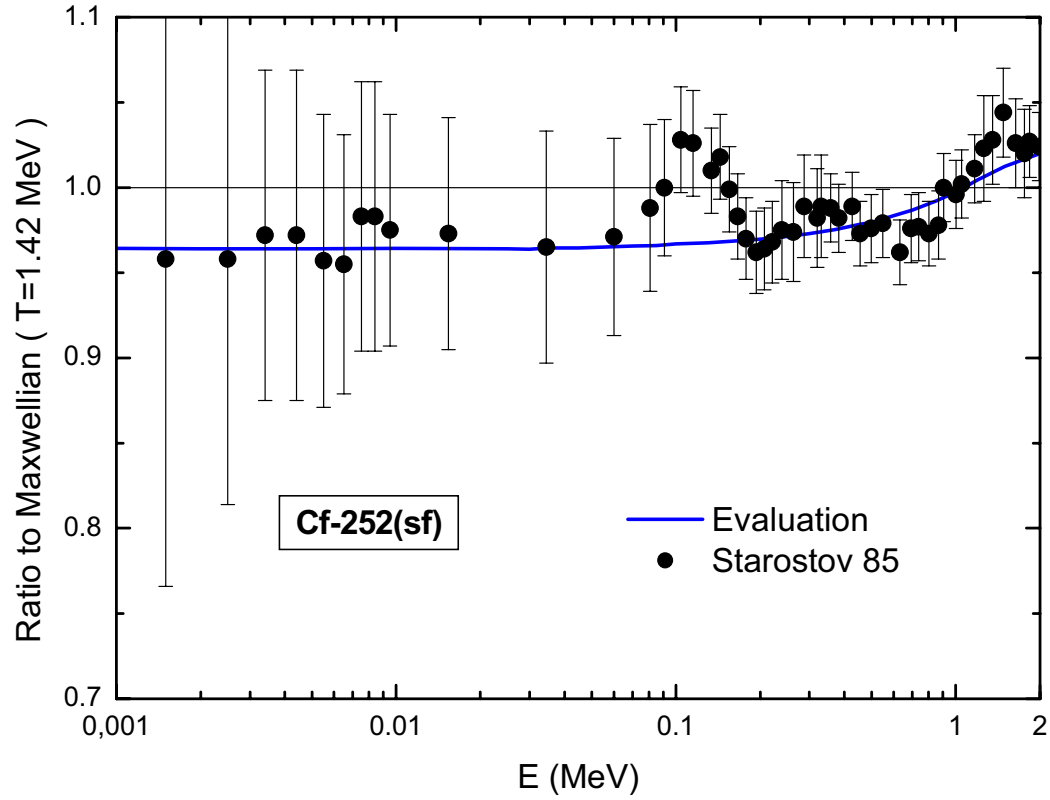
- **The smoothing of the data with a weighted spline function is a compromise and is only undertaken in absence of a theoretical model which adequately describes the low and high energy portion of the spectrum.**
- **The present (point data) evaluation is primary an evaluation of the available experimental database of six different TOF measurements of the neutron spectrum covering the energy range between 25 keV and 19.5 MeV.**
- **The complete set of evaluated point data forms an excellent basis for realistic tests and for improvements of theoretical models describing the fission neutron spectrum.**

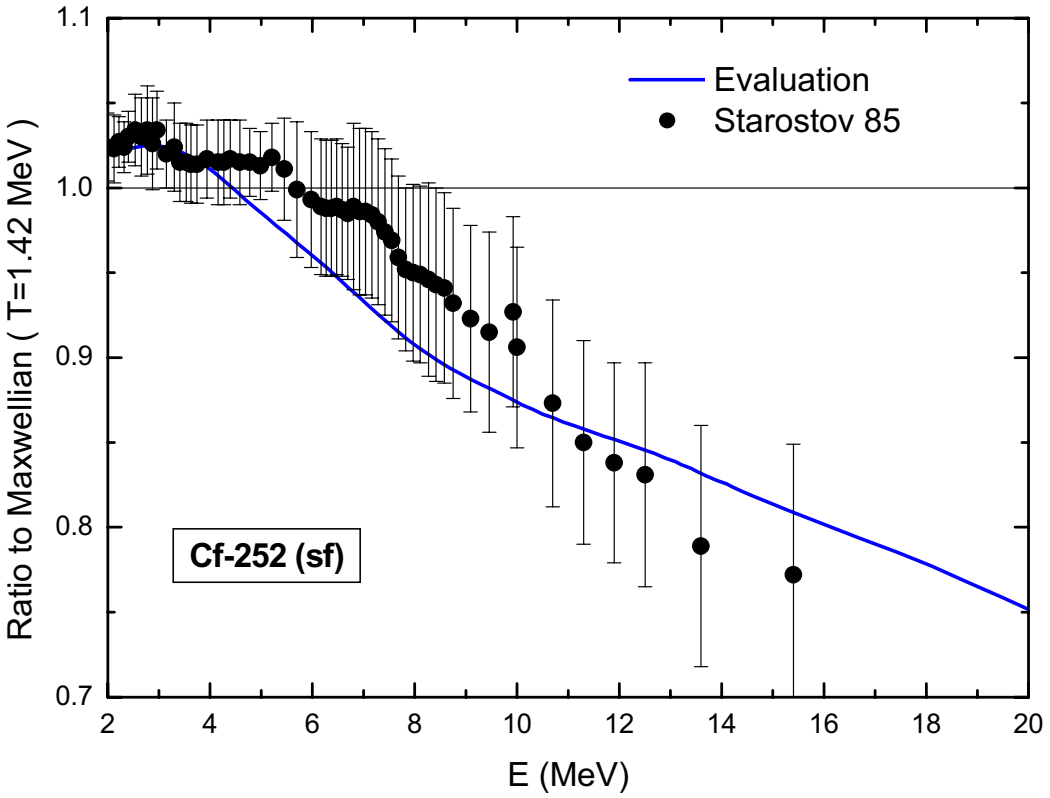
Experiments performed between 1989 and 2008

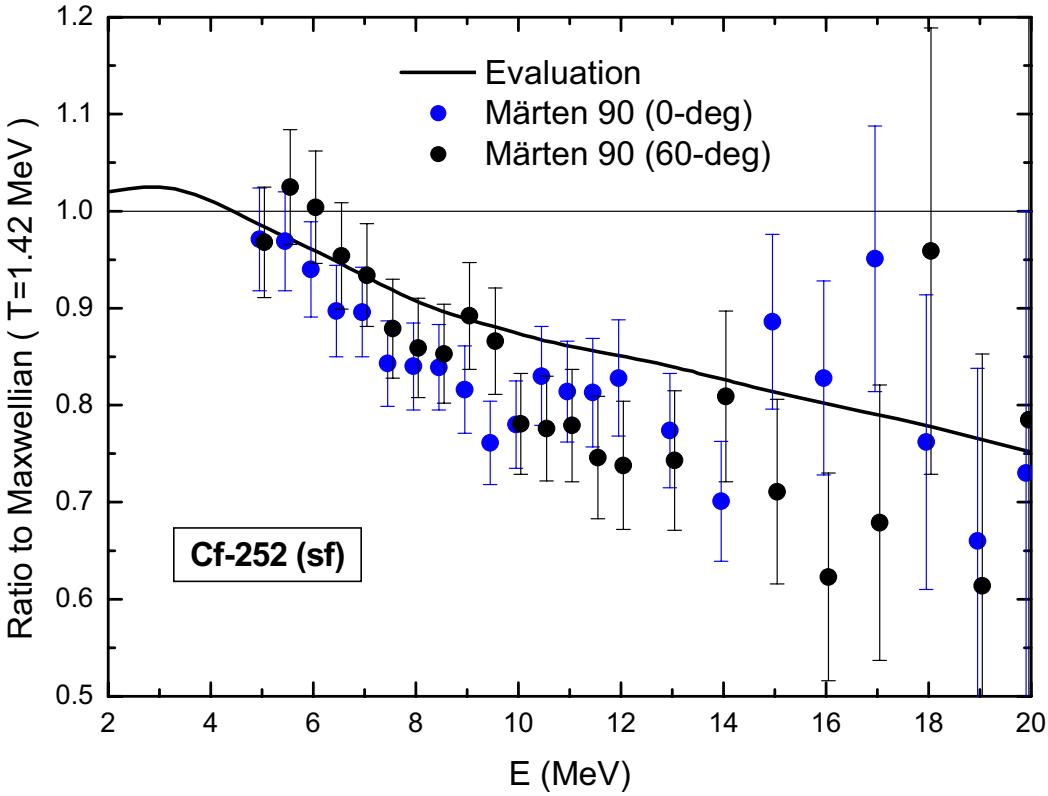
Authors	Reference	TOF (m)	Energy range (MeV)
Chalupka et al.	NSE 106 (1990) 367	2.80	9.00 - 18.94
Märten et al.	NSE 106 (1990) 353	3.28/ 5.91	5.00 – 20.00
Bao et al.	”50 Years with Fission”, Washington (1989), Vol. 2, p. 951	0.30	0.149 – 1.19
Coelho et al.	NIM/A 280 (1989) 270	**PR**	2.40 – 16.20
Starostov et al.	YK (3) (1985) 16, 6th All Union Conf. Kiev (1983) Vol. 2, p. 290	0.51/ 2.31/ 6.11	0.001 –15.40

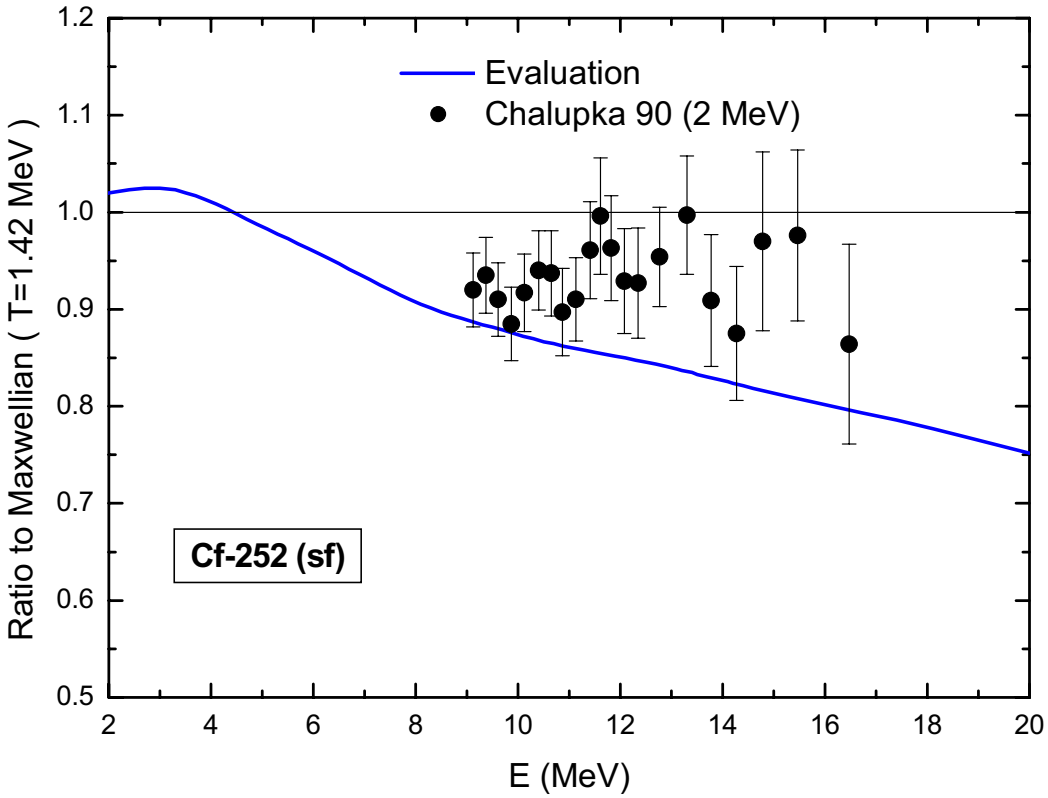

Cf-252(sf)
Evaluation
Bao 89
Ratio to Maxwellian (T=1.42 MeV)
E (MeV)
1.2
1.1
1.0
0.9
0.8
0.7
0.1
1
2

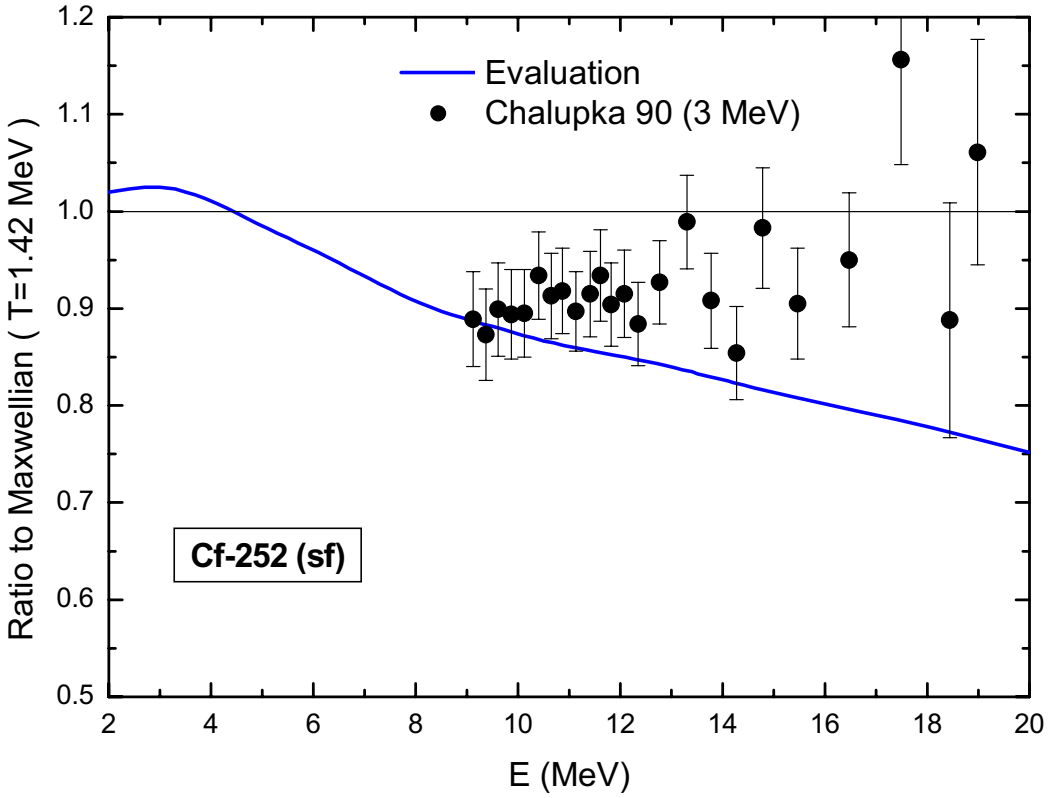

Evaluation
Coelho 89 (PR)
Cf-252 (sf)
Ratio to Maxwellian (T=1.42 MeV)
E (MeV)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
2
4
6
8
10
12
14
16
18
20


Ratio to Maxwellian (T=1.42 MeV)
E (MeV)
Cf-252(sf)
Evaluation
Starostov 85
1.1
1.0
0.9
0.8
0.7
0,001
0.01
0.1
1
2


Ratio to Maxwellian (T=1.42 MeV)
E (MeV)
Cf-252 (sf)
Evaluation
Starostov 85
1.1
1.0
0.9
0.8
0.7
2
4
6
8
10
12
14
16
18
20


Evaluation
Märten 90 (0-deg)
Märten 90 (60-deg)
Cf-252 (sf)
Ratio to Maxwellian (T=1.42 MeV)
E (MeV)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
2
4
6
8
10
12
14
16
18
20


Evaluation
Chalupka 90 (2 MeV)
Cf-252 (sf)
Ratio to Maxwellian (T=1.42 MeV)
E (MeV)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
2
4
6
8
10
12
14
16
18
20



Summary of the recent experiments

- **No recent experiment has been performed after 1990.**
- The data of Bao et al. are still quoted as preliminary and indicate difficulties in the proper correction of the lithium resonance.
- The data of the proton recoil experiment of Coelho et al. cannot contribute to an improvement of the evaluation.
- The experimental data of Starostov et al. are based on a series of measurements from 1983. These data did not pass the selection process in the previous evaluation. The data are mainly shown because the authors performed a similar series of measurements of ^{235}U + n(thermal).
- Only the high-energy data of Märten et al. and Chalupka et al. are worth to be considered in a future evaluation (see final summary).

Available documentation

"Properties of Neutron Sources", IAEA Advisory Group Meeting, Leningrad (USSR), 9 – 13 June 1986, **IAEA-TECDOC-410 (1987) p.158**

(Experimental database, evaluation procedure, corrections, results)

"Physics of Neutron Emission in Fission", IAEA Consultants' Meeting, Mito (Japan), 24 - 27 May 1988, **Report INDC(NDS)-220 (1989) p.305**

(Comparison of the input data with the result of the evaluation, comparison with theoretical models)

"Symposium on Nuclear Data Evaluation Methodology", Brookhaven National Laboratory (USA), 12 - 16 October 1992, (ed. C.L. Dunford), **World Scientific Publ. Co. (1993) p.247**

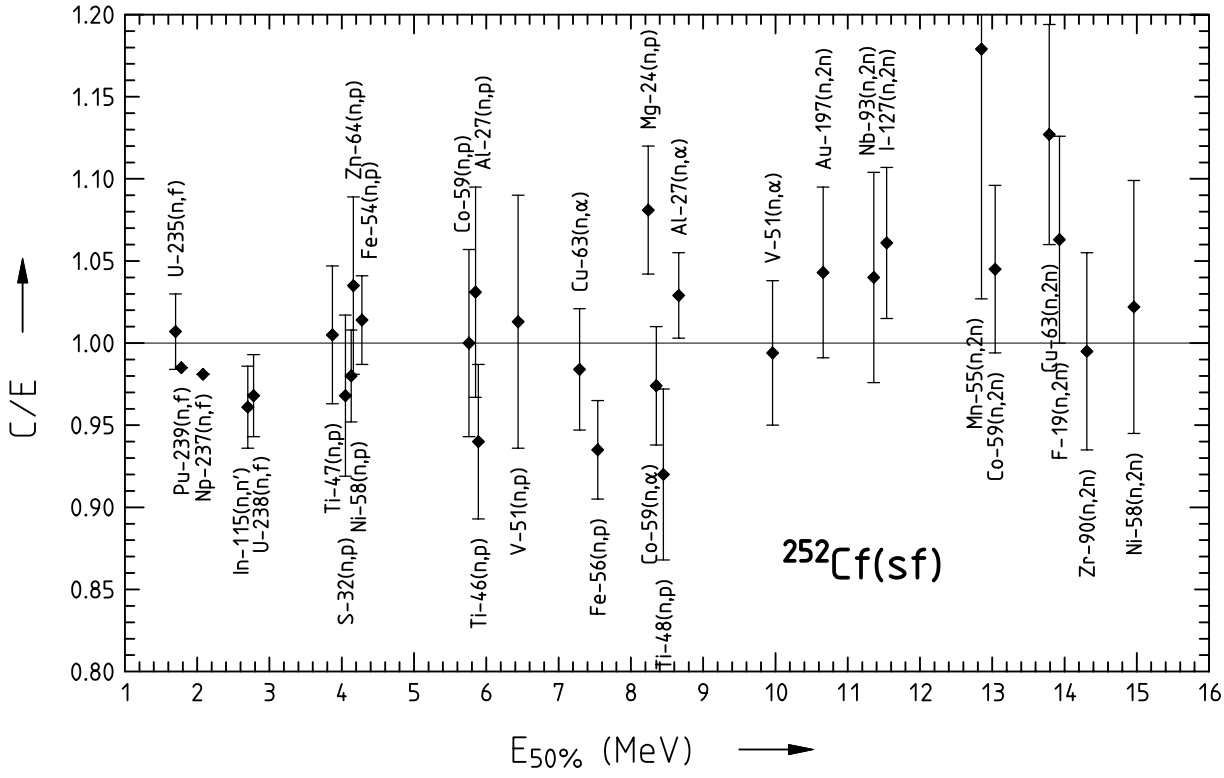
(Methodology, corrections, update of the evaluation with the recent data of Märten and Chalupka (only figures given), alternate evaluation methods)

Evaluation of $\langle\sigma\rangle_{exp}$ data in the neutron field of ^{252}Cf(sf)

No. of experiments:	**12**	
No. of data:	**70**	**(28 absolute)**
No. of reactions:	**35**	**(covariance matrix)**
Value of χ^2/f :	**1.01**	

References:	Iteration	Δ (%)
Covariance Meeting, ORNL, 7-9 Oct. 1992 NEA/NSC/DOC(93)3 (1993) p. 157	no	
Present data (2004, unpublished)	yes	0.00 – 0.14

Cf-252 (sf)		new evaluation		N(E) = (ENDF/B-VI)						
Reaction	E(50%) (MeV)	Experiment < σ > (mb)	error (%)	Calculation < σ > (mb)	total error (%)	σ(E) error (%)	N(E) error (%)	C/E	Δ C/E	Source σ(E)
U-235(n,f)	1.70	1.210E+03	1.20	1.218E+03	1.97	1.97	0.05	1.007	0.023	B-6 NDO
Pu-239(n,f)	1.78	1.812E+03	1.37	1.785E+03				0.985		B-6
Np-237(n,f)	2.08	1.361E+03	1.59	1.335E+03				0.981		B-6
In-115(n,n')	2.68	1.974E+02	1.37	1.898E+02	2.19	2.16	0.37	0.961	0.025	B-6 MF=10
U-238(n,f)	2.78	3.257E+02	1.64	3.154E+02	2.04	2.00	0.40	0.968	0.025	B-6 NDO
Ti-47(n,p)	3.85	1.927E+01	1.66	1.939E+01	3.83	3.78	0.62	1.006	0.042	IRDF-90.2
S-32(n,p)	4.08	7.254E+01	3.49	7.030E+01	3.68	3.60	0.74	0.969	0.049	IRDF-90.2
Ni-58(n,p)	4.13	1.175E+02	1.30	1.153E+02	2.52	2.41	0.72	0.981	0.028	B-6
Zn-64(n,p)	4.16	4.059E+01	1.65	4.207E+01	4.92	4.86	0.78	1.036	0.054	IRK-90
Fe-54(n,p)	4.28	8.684E+01	1.34	8.813E+01	2.29	2.15	0.78	1.015	0.027	B-6
Co-59(n,p)	5.76	1.690E+00	2.48	1.692E+00	4.23	4.07	1.14	1.001	0.049	B-6
Al-27(n,p)	5.96	4.880E+00	2.14	5.034E+00	5.85	5.74	1.15	1.032	0.064	B-6 NAV
Ti-46(n,p)	6.01	1.407E+01	1.77	1.325E+01	4.65	4.51	1.15	0.942	0.047	IRK-96
V-51(n,p)	6.44	6.488E-01	1.97	6.580E-01	7.34	7.23	1.25	1.014	0.077	B-6
Cu-63(n,α)	7.29	6.887E-01	1.96	6.785E-01	3.16	2.84	1.39	0.985	0.037	B-6
Fe-56(n,p)	7.54	1.465E+00	1.77	1.370E+00	2.62	2.18	1.46	0.935	0.030	B-6
Mg-24(n,p)	8.25	1.996E+00	2.44	2.159E+00	2.75	2.24	1.59	1.082	0.040	IRK-90
Co-59(n,α)	8.35	2.218E-01	1.88	2.162E-01	3.14	2.73	1.56	0.975	0.036	B-6
Ti-48(n,p)	8.39	4.247E-01	1.89	3.912E-01	5.35	5.11	1.57	0.921	0.052	IRK-96
Al-27(n,α)	8.64	1.016E+00	1.47	1.046E+00	2.11	1.35	1.62	1.030	0.026	IRK-90
V-51(n,α)	9.96	3.900E-02	2.21	3.880E-02	3.82	3.32	1.88	0.995	0.044	B-6
Au-197(n,2n)	10.63	5.506E+00	1.83	5.747E+00	4.62	4.15	2.02	1.044	0.052	IRK-90
Nb-93(n,2n)Nb-92m	11.36	7.490E-01	5.07	7.790E-01	3.46	2.65	2.23	1.040	0.064	IRK-90
I-127(n,2n)	11.75	2.069E+00	2.73	2.198E+00	3.30	2.28	2.38	1.062	0.045	IRDF-90.2
Mn-55(n,2n)	12.85	4.075E-01	2.33	4.811E-01	12.72	12.34	3.07	1.181	0.153	B-6
Co-59(n,2n)	13.04	4.051E-01	2.51	4.236E-01	4.18	2.63	3.25	1.046	0.051	IRK-90
Cu-63(n,2n)	13.78	1.844E-01	3.98	2.080E-01	4.42	1.67	4.09	1.128	0.067	IRK-90
F-19(n,2n)	14.00	1.612E-02	3.37	1.715E-02	4.87	2.11	4.39	1.064	0.063	IRK-90
Zr-90(n,2n)	14.40	2.210E-01	2.89	2.200E-01	5.28	1.56	5.04	0.995	0.060	IRK-90
Ni-58(n,2n)	14.94	8.952E-03	3.57	9.162E-03	6.66	2.92	5.99	1.023	0.077	IRK-90



Summary and conclusions

- Due to sufficient TOF measurements at high neutron energies, the integral data are not needed to improve the quality of the evaluation.
  (Advantage: the evaluated spectrum remains free from cross section data and can be used for cross section validation).
- The recent high-energy data of Märten et al. and Chalupka et al. show distinguished trends going into opposite directions. Only the **simultaneous** inclusion of both data sets in the evaluation will compensate large portions of this divergence. Compared to the previous evaluation, the spectrum values will slightly increase between 13 MeV and 20 MeV. The maximum deviation is + 10%, at 20 MeV neutron energy. Above 15 MeV, the errors are reduced by a factor of about 3.
- **The update of the evaluation will not really solve the remaining question of the valid spectral shape above 15 MeV neutron energy.**