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Evaluation excitation functions for ^{28}Si(n,p)^{28}Al, ^{31}P(n,p)^{31}Si, and ^{113}In(n,γ)^{114m}In reactions

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INTRODUCTION

Cross section data for $^{28}Si(n,p)^{28}Al$, $^{31}P(n,p)^{31}Si$ and $^{113}In(n,\gamma)^{114m}In$ reactions are needed for solving a wide spectrum of scientific and technical tasks. The excitation function of $^{28}Si(n,p)^{28}Al$ reaction refers to the nuclear data involved in fusion reactor design calculations. The $^{28}Si(n,p)^{28}Al$ reaction is interesting also as the monitor reaction for measurements at fusion facilities. Activation detectors on the basis of the $^{31}P(n,p)^{31}Si$ reaction are commonly used in the reactor dosimetry. The $^{113}In(n,\gamma)^{114m}In$ reaction is promising regarding reactor dosimetry application for two reasons. First, due to the ^{114m}In decay parameters which are rather suitable for activation measurements. Half-life of ^{114m}In is equal to $T_{1/2}= (49.51 \pm 0.01)$ days and gamma spectrum accompanying decay has only one line with energy 190.27 keV and intensity $(15.56 \pm 0.15)\%$. Second, the $^{113}In(n,\gamma)^{114m}In$ reaction rate may be measured by using one activation detector simultaneously with the $^{115}In(n,\gamma)^{116m}In$ reaction.

Preliminary analysis of existing evaluated excitation functions for $^{28}Si(n,p)^{28}Al$, $^{31}P(n,p)^{31}Si$ and $^{113}In(n,\gamma)^{114m}In$ reactions show that new evaluations are needed for all above mentioned reactions. This report is devoted to the preparation of the new evaluations of cross sections data and related covariance matrixes of uncertainties for the $^{28}Si(n,p)^{28}Al$, $^{31}P(n,p)^{31}Si$ and $^{113}In(n,\gamma)^{114m}In$ reactions.

1. METHOD OF EVALUATION OF THE REACTION EXCITATION FUNCTIONS

1.1. Sources of information used in the evaluation

In the process of evaluating cross sections and their uncertainties two common information sources were used for reactions $^{28}Si(n,p)^{28}Al$, $^{31}P(n,p)^{31}Si$ and $^{113}In(n,\gamma)^{114m}In$: available differential and integral experimental data. Differential and integral experimental data were taken mainly from EXFOR Library (Version April 2014). In those cases where the necessary information (e.g., decay data, reference to and numeric data about the monitor reactions etc.) was absent in the EXFOR, the information was taken from the original publications.

1.2. Analysis of experimental data

In the first step of evaluation all experimental data were analysed. During this procedure all experimental data, where possible, were corrected to the new recommended cross section data for monitor reactions used in the measurements and to the new recommended decay data.

Correction of experimental data to the new standards, in general, lead to decreasing the discrepancies in the experimental data and thus to decreasing the uncertainty in the evaluated cross section values. The needed information about standards used for correction of microscopic experimental data under investigation is given in the Table 1.1.

Recommended cross section data for monitor reactions used in the measurements of integral cross sections in ^{235}U thermal fission neutron spectrum and ^{252}Cf spontaneous fission neutron spectrum were taken from Refs. [1.10] [1.23-1.24]. Digital data for ^{235}U thermal fission and ^{252}Cf spontaneous fission neutron spectra were taken from Refs. [1.25] and [1.26], respectively.
Information about isotopic compositions of the elements was taken from Ref. [1.27].

Table 1.1. Data used as standards for correction of microscopic experimental cross sections.

Monitor reaction	Cross section used as standard	Half-life of residual nuclei	Radiation mode and energy, keV	Emission Probability per decay
^{1}H(n,n)^{1}H	Carlson+ [1.1]			
^{6}Li(n,t)^{4}He	Carlson+ [1.1]			
^{27}Al(n,α)^{24}Na	Zolotarev [1.2]	14.997 (12) h	Gamma 1368.63 Gamma 2754.01	0.999936 (15) [1.12] 0.99855 (5) [1.12]
^{27}Al(n,p)^{27}Mg	Zolotarev+ [1.3]	9.458 (12) m	Gamma 843.76 Gamma 1014.44	0.718 (4) [1.13] 0.280 (4) [1.13]
^{31}P(n,α)^{28}Al	Gopych+ [1.4]	2.245 (2) m	Gamma 1778.99 Beta- 2863.27	[1.14] 0.99990 (10) [1.14]
^{56}Fe(n,p)^{56}Mn	Zolotarev [1.5]	2.5789 (1) h	Gamma 846.76 Gamma 1810.73	0.9887 (3) [1.13] 0.2719 (79) [1.13]
^{59}Co(n,γ)^{60}Co	Mughabghab [1.6]	1925.28 (14) d	Gamma 1173.228 Gamma 1332.492	0.9985 (3) [1.15] 0.999826 (6) [1.15]
^{63}Cu(n,2n)^{62}Cu	Zolotarev [1.7]	9.67 (3) m	Beta+ 2925.8 Gamma 511 Gamma 1172.94	0.9760 (3) [1.16] 1.9566 (5) [1.16] 0.00342 (5) [1.16]
^{93}Nb(n,2n)^{92m}Nb	Zolotarev [1.8]	10.15 (2) d	Gamma 934.44	0.9907 (4) [1.13]
^{115}In(n,n')^{115m}In	Zolotarev+ [1.9]	4.486 (4) h	Gamma 336.24	0.458 (22) [1.17]
^{115}In(n,γ) ^{116m}In	Zolotarev [1.10]	54.29 (17) m	Gamma 416.90 Gamma 1097.28 Gamma 1293.56	0.272 (4) [1.18] 0.585 (8) [1.18] 0.848 (12) [1.18]
^{127}I(n,γ)^{128}I	Zolotarev [1.11]	24.99 (2) m	Gamma 442.90	0.169 (17) [1.13]
^{197}Au(n,γ)^{198}Au	Mughabghab [1.6] Carlson+ [1.1]	2.6947 (3) d	Gamma 411.802	0.9562 (4) [1.19]
^{235}U(n,f)	Carlson+ [1.1]			
^{238}U(n,f)	Carlson+ [1.1]			

Comment for Table 1.1: for beta transition the end-point value of energy is given.

Table 1.2. Data used as standards for correction of integral experimental cross sections measured in ^{235}U thermal fission and ^{252}Cf spontaneous fission neutron spectra.

Monitor Reaction	Cross section used as standard, mb	Half-life for residual nuclei	Radiation mode and energy, keV	Emission Probability per decay
^{27}Al(n,α)^{24}Na	0.7007±1.28% [1.23] U 1.016±1.28% [1.24] Cf	14.997 (12) h	Gamma 1368.63 Gamma 2754.01	0.999936(15) [1.12] 0.99855 (5) [1.12]
^{32}S(n,p)^{32}P	69.08±1.97% [1.23] U	14.268 (5) d	Beta- 1710.66	1.000 [1.20]
^{54}Fe(n,p)^{54}Mn	78.09±1.50% [1.10] U	312.05 (4) d	Gamma 834.848	0.999760(10) [1.21]
^{56}Fe(n,p)^{56}Mn	1.079±1.54% [1.23] U	2.5789 (1) h	Gamma 846.754 Gamma 1810.72	0.9887 (3) [1.13] 0.2719 (79) [1.13]
^{58}Ni(n,p)^{58}Co	108.2±1.30% [1.23] U	70.86 (6) d	Gamma 511 Gamma 810.78	0.298 (4) [1.22] 0.99450 (10) [1.22]
^{115}In(n,n')^{115m}In	187.8±1.23% [1.23] U 197.4±1.37% [1.24] Cf	4.486 (4) h	Gamma 336.24	0.458 (22) [1.17]
^{238}U(n,f)	325.7±1.64% [1.24] Cf			

Comments for Table 1.2: Symbol "U" – means ^{235}U thermal fission neutron spectrum,

Symbol "Cf" – means ^{252}Cf spontaneous fission neutron spectrum.

1.3. Theoretical model calculation cross-section values for the dosimetry reactions

The theoretical model calculation was used as additional source of cross-section information for reactions with poor experimental data. In our case, the theoretical model calculation was carried out for the determination of the ^{113}In(n,γ)^{114m}In reaction excitation function above 2 keV.

For theoretical description of the excitation function, the ^{113}In(n,γ)^{114m}In reaction optical-statistical method was used while taking into account consistently the contribution of the direct, preequilibrium and statistical equilibrium processes in the different outgoing channels.

The practical calculations of cross sections were made by means of a modified version of the GNASH code [1.28]. The modified GNASH code is differing in general from the original GNASH code [1.29]. The modified version includes subroutine which permits to take into account the neutron width fluctuation. Furthermore, the modified GNASH code has a mode which permits to calculate the cross-section of population of individual levels excited in the investigated reaction. This capability is very important to calculate the ^{113}In(n,γ)^{114g}In and ^{113}In(n,γ)^{114m}In reaction cross sections.

The calculation of penetrability coefficients for neutrons was made on the basis of a generalized optical model, which permits to estimate the cross sections for the direct excitations of collective low-lying levels. The ECIS coupled channel deformed optical model code [1.30] was used for these calculations. The optical coefficients of proton and alpha particle penetrabilities were determined by means of the SCAT2 code [1.31].

The data on discrete levels parameters for ^{114}In and all residual nuclei were obtained from Ref. [1.13]. Unknown branching ratios were estimated on the basis of statistical calculations of the possible E1, E2, and M1 gamma-ray transitions. Intensities of such transitions were calculated in accordance with the radiation strength functions recommended in Ref. [1.32].

Continuum level densities were represented with the Gilbert-Cameron [1.33] model using the Cook parameters [1.34] (mode IBSF=1 in the GNASH code). The calculation of gamma-ray transition probabilities in the continuum region of excited states of all nuclei under consideration was made in the frame of hypothesis of domination of giant dipole resonance with parameters of radiative strength function from Kopecky-Uhl systematic [1.35]. Recommended parameters of giant dipole resonances were taken from Ref. [1.36].

By means of the modified GNASH code cross section values of the ^{113}In(n,γ)^{114m}In reaction were calculated from 2 keV to 20 MeV.

1.4. Statistical analysis of cross-sections from the database

The method of statistical analysis of correlated data used to evaluate the excitation functions of dosimetry reactions ^{28}Si(n,p)^{28}Al, ^{31}P(n,p)^{31}Si and ^{113}In(n,γ)^{114m}In was described in the IAEA NDS Reports [1.2], [1.7]. Detailed description of the method and PADE-2 code may be found in Refs. [1.37-1.39].

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2. Evaluation of the ^{28}Si(n,p)^{28}Al reaction excitation function

The abundance of ^{28}Si isotope in natural silicon and the half-life of ^{28}Al are 92.2297 ± 0.0007 atom percent and (2.245 ± 0.002) min, respectively. Nucleus ^{28}Al has 100% β^- decay mode. For the determination of ^{28}Si(n,p)^{28}Al reaction rate mainly the 1778.987 keV (I_γ = 1.000) gamma line is used. The 1241.80 keV β^- rays with end-point energy of 2863.27 keV having intensity of $I_{\beta-}$= 0.99990 ± 0.000010. Recommended decay data for ^{28}Al - half-life and gamma ray emission probability per decay, I_γ - were taken from Ref. [2.1].

The excitation function of the ^{28}Si(n,p)^{28}Al reaction was analysed for the incident neutron energies from the threshold (E_{th} = 3.99924 MeV) to 21 MeV. During this analysis 43 works [2.2-2.44] published in the period from 1953 to 2011 were reviewed. In the process of reviewing the experimental data published in Refs. [2.6], [2.11-2.12], [2.14-2.16], [2.18-2.23], [2.25-2.30], [2.32-2.33], [2.35-2.36] and [2.38-2.43] were corrected to the new recommended cross sections for monitor reactions used in the measurements and to the new recommended decay data. Cross section measured by Janczyszyn [2.29] at the neutron energy 14.90 MeV was renormalized to the cross-section value of (128.13 ± 6.09) mb for the ^{31}P(n,α)^{28}Al monitor reaction. This value was obtained from the corrected experimental data of Gopych et al. [2.45].

Special correction was applied to the experimental data in Refs. [2.4-2.5], [2.8], [2.9], [2.13], [2.38] and [2.43].

Experimental data of Marion et al. [2.4], Mainsbridge et al. [2.9] and Bass et al. [2.13] were renormalized to the results of precise measurements of W. Mannhart and D. Schmidt [2.42] in the overlapping energy ranges. Correction factors for the experimental data [2.4], [2.9], [2.13] were Fc = 0.61225, Fc = 0.52921, Fc = 0.77906, respectively. Experimental data of Furuta et al. [2.43] were also renormalized to the results of precise measurements by W. Mannhart and D. Schmidt via corrected data of Mainsbridge et al. [2.9] in the overlapping energy 5.060 - 5.930 MeV, Fc = 0.64855.

Kern et al. [2.5] investigated the ^{28}Si(n,p)^{28}Al reaction excitation function in the problem energy range 12 - 18 MeV. Unfortunately, during the cross section measurements neutron flux density was not constant in time. This is the main reason for widely scattered data. Measured in the energy range 12.33 - 18.24 MeV the widely scattered data of Kern et al. [2.5] were separated for five sets of data with approximately equivalent neutron flux density in the process of irradiation. Each set of the data had been renormalized to the corresponded cross section value determined from representative experimental data [2.33], [2.40], [2.42] in the interval 13 - 14 MeV.

Cross section data obtained by Jeronymo et al. [2.8] at incident neutron energies 12.55, 13.55, 14.90, 16.50, 19.60 MeV were renormalized to the representative experimental data of Hongyu Zhou et al. [2.44] at 14.90 MeV, Fc = 1.37274.

Experimental data by Y. Kasugai et al. [2.38] were renormalized for the integral of cross section calculated from the representative experimental data of Ikeda et al. [2.33] in the overlapping energy range 13.40 - 14.87 MeV, Fc = 1.09426.

Cross section measured by Klochkova et al. [2.34], [2.37] at 14.90 MeV neutron energy was corrected for the contribution from reactions ^{29}Si(n,p)^{29}Al and ^{30}Si(n,p)^{30}Al. Cross sections for these reactions at 14.90 MeV were taken from the Refs. [2.42] and [2.46], respectively.

All experimental data obtained by using the activation method and samples of natural isotopic composition (except [2.33], [2.38], [2.41], [2.42]) were corrected above 12 MeV for contribution from the ^{29}Si(n,x)^{28}Al reaction where x = (n+p) + (p+n) + d, i.e. the sum of the outgoing particles.

Excitation function for the ^{29}Si(n,x)^{28}Al reaction from threshold to 21 MeV and related uncertainties were evaluated in this work on the basis of experimental data given in the Refs. [2.33], [2.38] and [2.41]. These experimental data were also corrected to the new standards (see Table 1.1 in Section 1). Evaluated excitation function for the reaction ^{29}Si(n,x)^{28}Al from threshold to 21 MeV in comparison with experimental data is shown in Fig. 2.1 and presented in Table 2.1.

Table 2.1. Evaluated cross sections and their uncertainties for the ^{29}Si(n,x)^{28}Al reaction in the NEUTRON energy range from threshold to 21 MeV.

Neutron energy (MeV) from to	Cross section (mb)	Uncertainty (%)	Neutron energy (MeV) from to	Cross section (mb)	Uncertainty (%)
10.461 - 12.500	0.418	23.99	16.750 - 17.000	98.224	8.94
12.500 - 13.000	3.239	5.41	17.000 - 17.250	112.007	8.45
13.000 - 13.250	4.989	4.87	17.250 - 17.500	125.924	8.02
13.250 - 13.500	6.354	4.48	17.500 - 17.750	139.641	7.83
13.500 - 13.750	7.915	4.26	17.750 - 18.000	152.850	7.92
13.750 - 14.000	9.745	4.28	18.000 - 18.250	165.292	8.20
14.000 - 14.250	11.951	4.41	18.250 - 18.500	176.539	8.50
14.250 - 14.500	14.668	4.45	18.500 - 18.750	187.151	8.69
14.500 - 14.750	18.056	4.34	18.750 - 19.000	196.369	8.68
14.750 - 15.000	22.285	4.24	19.000 - 19.250	204.409	8.47
15.000 - 15.250	27.523	4.55	19.250 - 19.500	211.302	8.11
15.250 - 15.500	33.919	5.43	19.500 - 19.750	217.109	7.76
15.500 - 15.750	41.583	6.67	19.750 - 20.000	221.912	7.60
15.750 - 16.000	50.572	7.87	20.000 - 20.250	225.805	7.85
16.000 - 16.250	60.868	8.78	20.250 - 20.500	228.887	8.66
16.250 - 16.500	72.374	9.25	20.500 - 20.750	231.255	10.02
16.500 - 16.750	84.910	9.27	20.750 - 21.000	233.002	11.83

The excitation function for the ^{28}Si(n,p)^{28}Al reaction from threshold to 21 MeV and related uncertainties were evaluated on the basis of experimental data given in Refs. [2.4-2.5], [2.7-2.9], [2.13], [2.16-2.19], [2.21-2.22], [2.25-2.33] and [2.36-2.45].

A statistical analysis of input cross section data was carried out by means of PADE-2 code. The rational function was used as a model function.

Uncertainties in cross sections for the evaluated ^{28}Si(n,p)^{28}Al reaction excitation function are given in the form of a relative covariance matrix for 47-neutron energy groups (LB = 5). The covariance matrix of uncertainties was calculated simultaneously with the recommended cross-section data by means of the PADE-2 code and tested additionally by the COVEIG code [2.57]. The six-digit eigenvalues of the relative covariance matrix presented in File-33 are as follows:

```
3.51564E-06    3.52823E-06      3.54907E-06      3.57789E-06
3.61472E-06    3.66117E-06      3.71115E-06      3.77705E-06
3.83668E-06    3.92041E-06      3.99476E-06      4.07835E-06
4.19493E-06    4.30483E-06      4.41557E-06      4.55429E-06
4.93802E-06    5.62141E-06      6.59375E-06      8.10454E-06
1.03073E-05    1.34009E-05      1.76791E-05      2.35391E-05
3.11619E-05    3.32529E-05      4.37642E-05      1.54908E-04
2.25270E-04    6.60505E-04      7.08582E-04      8.01326E-04
8.79098E-04    9.45802E-04      1.02200E-03      1.18158E-03
1.42206E-03    1.51558E-03      1.59922E-03      1.95391E-03
3.05175E-03    4.12368E-03      7.39707E-03      1.53135E-02
1.86107E-02    5.42632E-02      6.77829E-02
```

The group cross sections calculated from the evaluated excitation function and related uncertainties for the ^{28}Si(n,p)^{28}Al reaction are given below in Table 2.2. Boundaries of the neutron energy groups are the same as in the File-33.

Table 2.2. Evaluated cross sections and their uncertainties for the ^{28}Si(n,p)^{28}Al reaction in the NEUTRON energy range from threshold to 21 MeV.

Neutron energy (MeV) from to	Cross section (mb)	Uncertainty (%)	Neutron energy (MeV) from to	Cross section (mb)	Uncertainty (%)
3.999 - 5.000	2.698	25.98	12.250 - 12.500	264.996	3.27
5.000 - 5.500	15.333	7.81	12.500 - 12.750	268.053	3.11
5.500 - 6.000	41.087	4.91	12.750 - 13.000	270. 954	2.94
6.000 - 6.250	75.509	3.76	13.000 - 13.250	273.258	2.75
6.250 - 6.500	128.945	3.67	13.250 - 13.500	274.525	2.56
6.500 - 6.750	147.097	4.21	13.500 - 13.750	274.345	2.36
6.750 - 7.000	186.436	3.87	13.750 - 14.000	272.394	2.19
7.000 - 7.250	188.253	3.68	14.000 - 14.250	268.489	2.04
7.250 - 7.500	223.400	3.68	14.250 - 14.500	262.618	1.95
7.500 - 7.750	220.082	3.83	14.500 - 14.750	255.803	1.95
7.750 - 8.000	259.903	3.90	14.750 - 15.000	248.262	2.05
8.000 - 8.250	194.510	4.62	15.000 - 15.500	234.510	2.40
8.250 - 8.500	209.158	3.70	15.500 - 16.000	215.396	3.14
8.500 - 8.750	249.735	3.87	16.000 - 16.500	197.286	3.98
8.750 - 9.000	221.373	4.45	16.500 - 17.000	179.390	4.80
9.000 - 9.500	228.627	3.04	17.000 - 17.500	161.556	5.50
9.500 - 10.000	241.025	3.08	17.500 - 18.000	144.536	6.06
10.000 - 10.500	262.919	3.27	18.000 - 18.500	128.860	6.55
10.500 - 11.000	254.631	3.45	18.500 - 19.000	114.841	7.12
11.000 - 11.250	251.901	3.55	19.000 - 19.500	102.600	8.00
11.250 - 11.500	261.808	3.57	19.500 - 20.000	92.120	9.44
11.500 - 11.750	259.798	3.55	20.000 - 20.500	83.288	11.64
11.750 - 12.000	260.206	3.49	20.500 - 21.000	75. 944	14.68
12.000 - 12.250	262.217	3.40			

Uncertainties in the evaluated ^{28}Si(n,p)^{28}Al excitation function range from 1.95% to 25.98%. The smallest uncertainty of 1.95% in the evaluated cross sections is observed in the neutron energy range 14.25 – 14.75 MeV. Uncertainties in cross sections exceeding 10% can be observed in the energy range 3.999 - 5.000 and 20 - 21 MeV.

The evaluated excitation function for the ^{28}Si(n,p)^{28}Al reaction in the neutron energy range from threshold to 21 MeV is shown in Fig. 2.2 in comparison with the equivalent data from ENDF/B-VII.1 and EAF-2010 libraries and corrected experimental data. The same information but in the narrow neutron energy ranges from 4 to 7 MeV and from 7 to 9.2 MeV is shown in Fig. 2.3 and Fig. 2.4, respectively.

Integral experiments for the ^{28}Si(n,p)^{28}Al reaction were described in the works of [2.47-2.56]. The main part of experiments was carried out in the neutron fields with ^{235}U thermal fission neutron spectrum [2.48-2.51] and [2.55-2.56]. Two experiments [2.52] and [2.54] were performed in the field of ^{252}Cf spontaneous fission neutron spectrum. In the experiment performed by Cohen [2.47], the ^{28}Si(n,p)^{28}Al reaction cross section was measured in the neutron spectrum from the Be(d,n) source. The minimal and the maximal energies in the neutron spectrum were 3.9 MeV and 18 MeV, respectively. Vaenskae and Rieppo [2.53] measured the ^{28}Si(n,p)^{28}Al reaction cross section in the neutron field produced by the ^{241}Am-Be source. The broad spectrum of neutrons from the ^{241}Am-Be source have their maximal energy at 11 MeV. Unfortunately, the experimental data of [2.47] and [2.53] could not be used for verification of evaluated microscopic cross sections due to the absence of well determined neutron spectrum data.

Experimental data obtained for the ^{235}U thermal fission neutron spectrum and the ^{252}Cf spontaneous fission neutron spectrum were corrected to the new recommended cross sections for monitor reactions and decay data given in Table 1.2. The measurements carried out by Kimura et al. [2.49], Grigor'ev and Yaryna [2.51], and Arribere et al. [2.55] in the ^{235}U thermal fission neutron spectrum give for the ^{28}Si(n,p)^{28}Al reaction the integral cross section values: (5.331 ± 0.329) mb, (5.395 ± 0.270) mb and (5.537 ± 0.206) mb, respectively. Corrected to the new standards, experimental data of Bruggeman et al. [2.48] and Pfrepper and Raitschev [2.50] arrive at higher cross-section values: (7.099 ± 0.165) mb and (6.482 ± 0.270) mb, respectively.

Two measurements on the ^{28}Si(n,p)^{28}Al reaction cross section in the ^{252}Cf spontaneous fission neutron spectrum were performed by Csikai and Dezső [2.52], [2.54]. Corrected to the new standards, a value of (6.907 ± 0.305) mb from the second publication [2.54] was accepted. The preliminary result (9.320 ± 0.531) mb given in Ref. [2.52] has been rejected.

As the most representative, the integral experimental data of [2.49], [2.51], [2.54] and [2.55] as the most representative were selected to benchmark the results of new evaluation for the ^{28}Si(n,p)^{28}Al reaction excitation function. Calculated averaged cross sections over the ^{235}U thermal fission neutron spectrum and ^{252}Cf spontaneous fission neutron spectrum are compared with ENDF/B-VII.1, EAF-2010 and experimental data in Table 2.3.

Table 2.3 Calculated and measured averaged cross sections for THE ^{28}Si(n,p)^{28}Al reaction in ^{235}U thermal fission and ^{252}Cf spontaneous fission neutron spectra.

Type of neutron field	Averaged cross section, mb		90% response function, MeV	C/E
	Calculated	Measured		
^{235}U thermal fission neutron spectrum	5.4836 [A] 7.0330 [B] 5.6641 [C]	5.470 ± 0.168 [*]	5.30 – 10.30 5.20 – 10.10 5.20 – 10.30	1.00249 1.28574 1.03548
^{252}Cf spontaneous fission neutron spectrum	7.1173 [A] 9.0353 [B] 7.3270 [C]	6.900 ± 0.437 [2.54]	5.40 – 10.80 5.20 – 10.60 5.20 – 10.80	1.03149 1.30946 1.06188

[A] - Present evaluation
[B] - ENDF/B-VII.1
[C] - EAF-2010
* - average-weighted value obtained from experimental data [2.49], [2.51] and [2.55].

The 90% response function shows the neutron energy range where the investigated excitation function is tested in the benchmark spectrum.

In the last column gives the value of C/E which is the ratio of the calculated to experimental cross sections.

The C/E values obtained for the ^{235}U thermal fission and ^{252}Cf spontaneous fission neutron spectra show that the ^{28}Si(n,p)^{28}Al integral cross sections calculated from newly evaluated excitation function agree well with the relevant experimental data. In the case of the $<\sigma>_{U\text{-}235}$ and $<\sigma>_{Cf\text{-}252}$ cross sections calculated from the EAF-2010 excitation function the agreement with the relevant experimental values is worse. Discrepancies between experimental data and calculated ENDF/B-VII.1 values are very large: 28.6 % and 30.9 %, respectively.

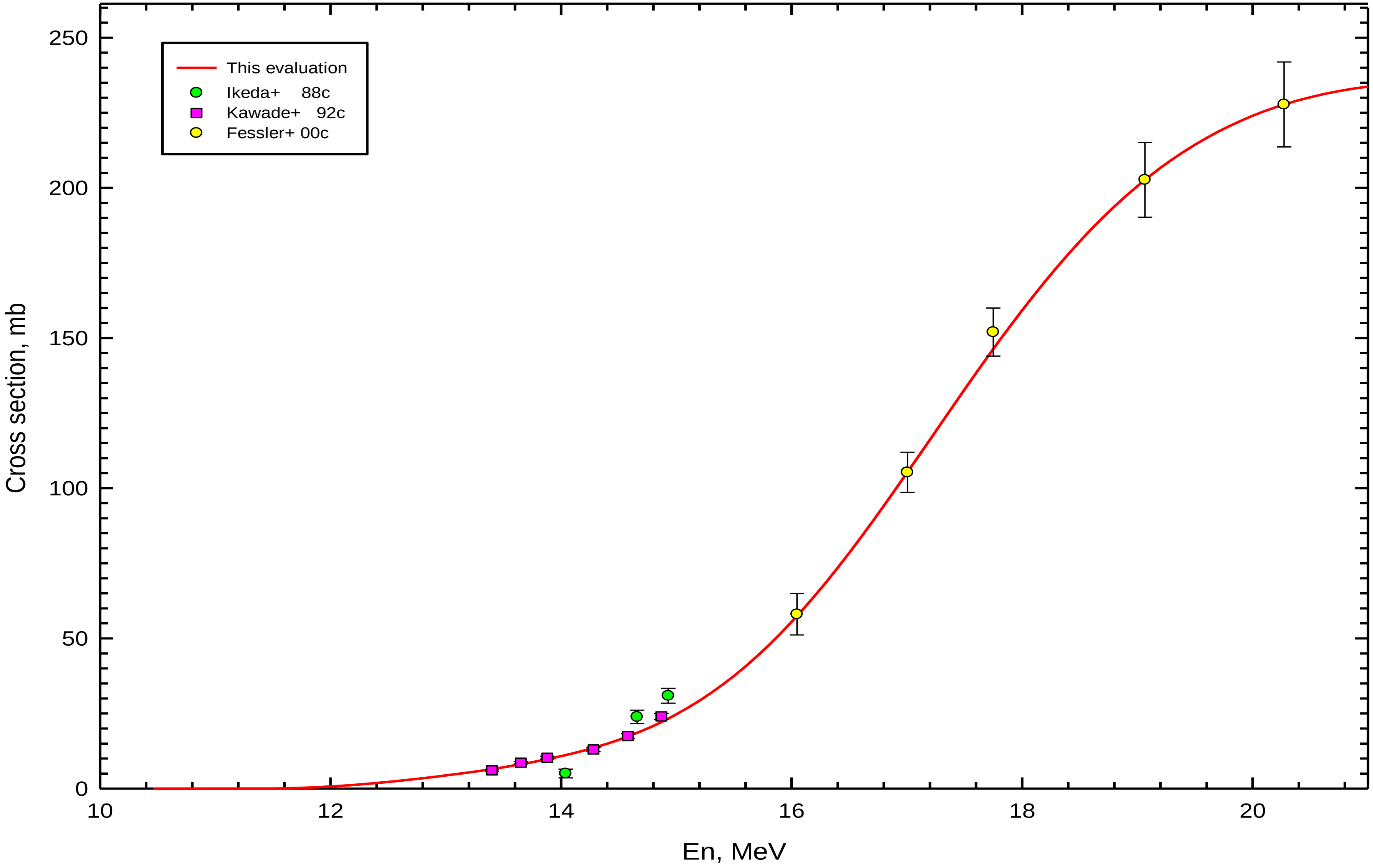

Fig. 2.1. Evaluated ^{29}Si(n,np+pn+d)^{28}Al reaction excitation function in the energy range from threshold to 21 MeV in comparison with corrected experimental data.

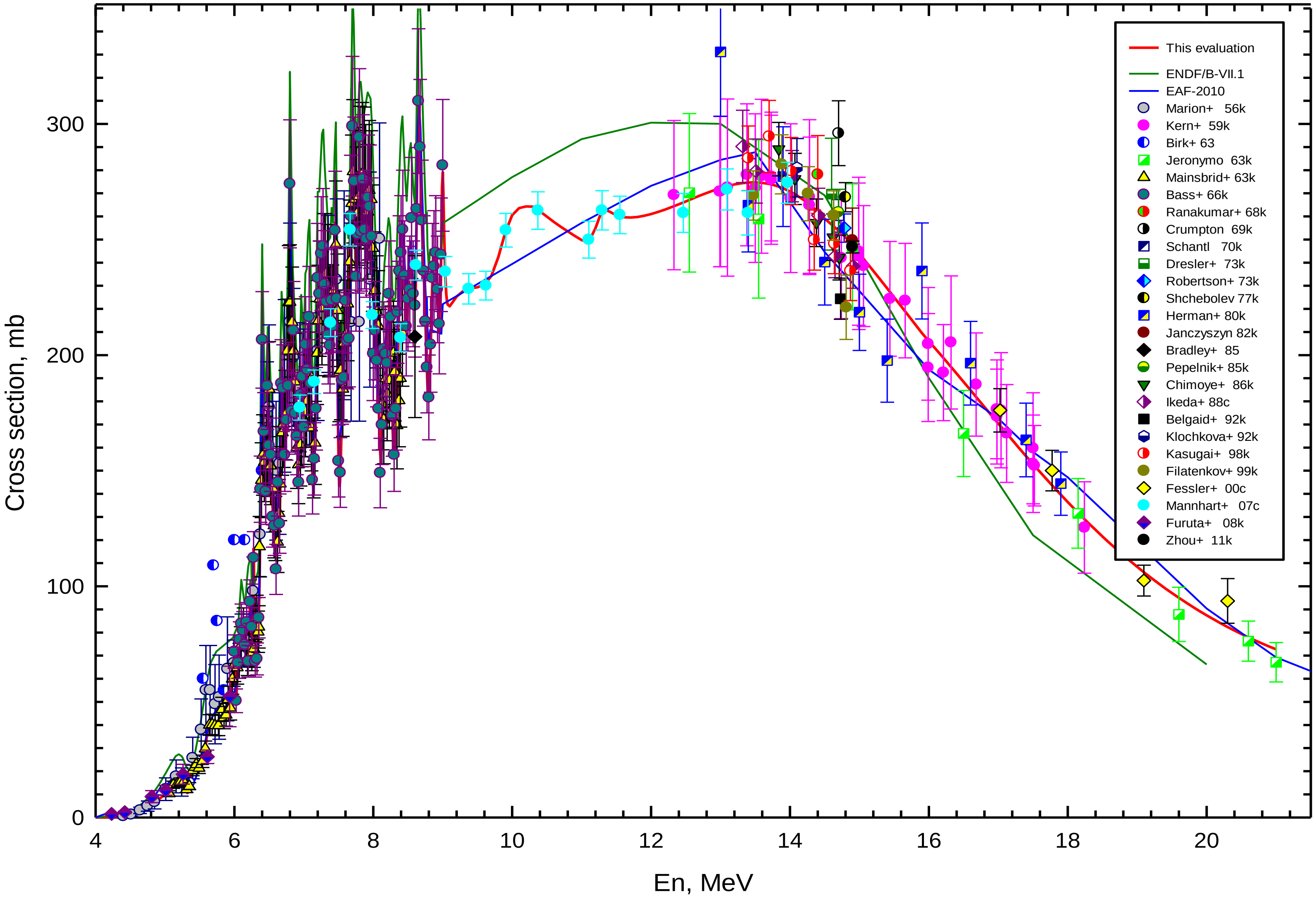

Fig. 2.2. Evaluated ^{28}Si(n,p)^{28}Al reaction excitation function in the energy range from threshold to 21 MeV in comparison with equivalent data from ENDF/B-VII.1, EAF-2010 and corrected experimental data.

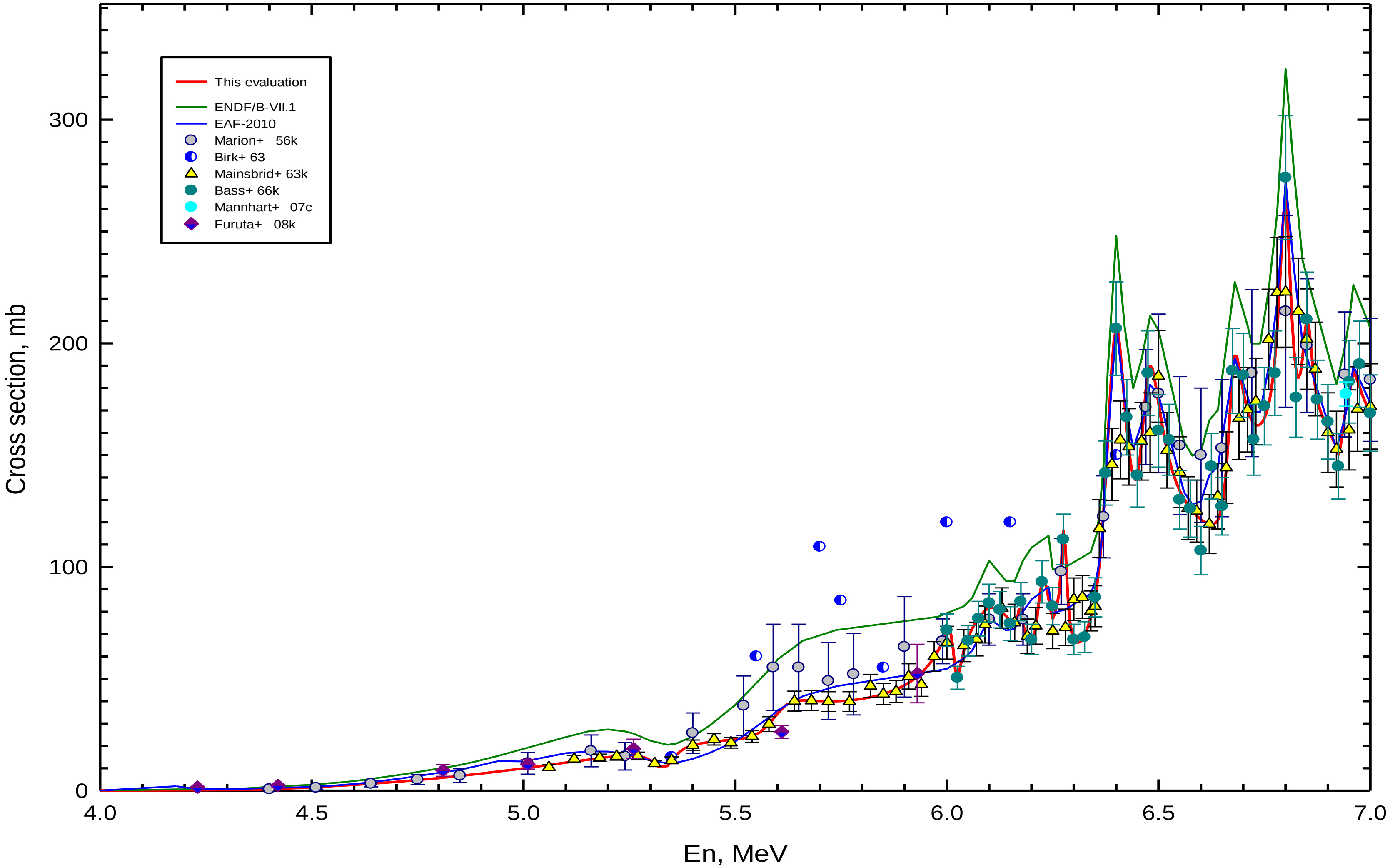

Fig. 2.3. Evaluated ^{28}Si(n,p)^{28}Al reaction excitation function in the energy range 4.0 – 7.0 MeV in comparison with equivalent data from ENDF/B-VII.1, EAF-2010 and corrected experimental data.

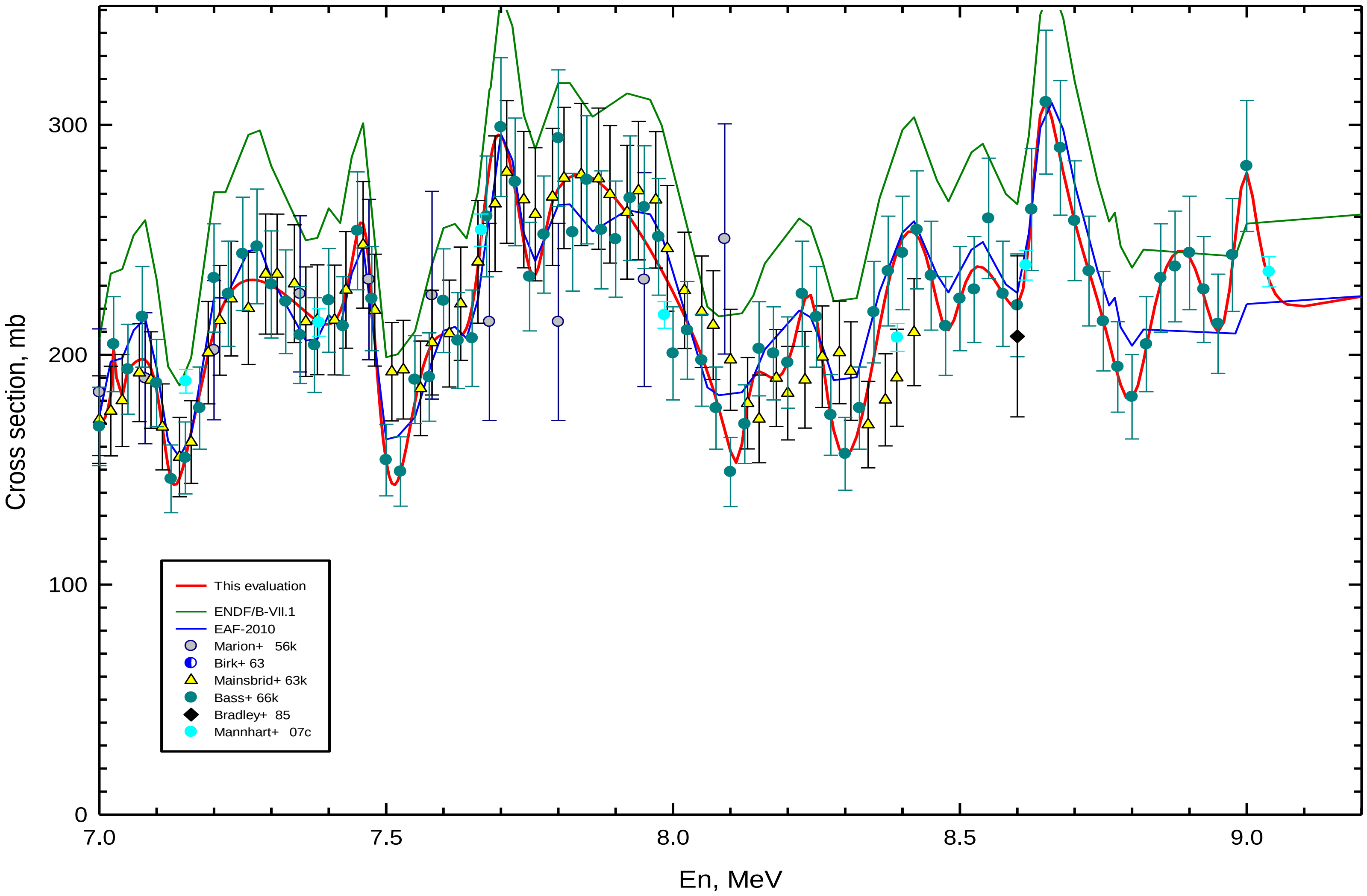

Fig. 2.4. Evaluated $^{28}Si(n,p)^{28}Al$ reaction excitation function in the energy range 7.0 – 9.2 MeV in comparison with equivalent data from ENDF/B-VII.1, EAF-2010 and corrected experimental data.

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3. EVALUATION OF THE ^{31}P(N,P)^{31}SI REACTION EXCITATION FUNCTION

The isotopic abundance of ^{31}P in natural phosphorus is 100 atom percent, and the ^{31}Si obtained via the (n,p) reaction undergoes a 100 % via β^- decay mode with a half-life of (157.36 ± 0.26) minutes. The ^{31}P(n,p)^{31}Si reaction rate is usually measured by detecting beta particles with end-point energy 1491.50 keV and total beta intensity (99.94463 ± 0.00007)%. The mean beta-energy is equal to 595.93 keV. Sometimes the ^{31}P(n,p)^{31}Si reaction rate is measured by detecting the 1266.2-keV gamma radiation, $I_\gamma = (0.0554 \pm 0.0007)$ %. Recommended decay data for ^{31}Si - half-life and beta, gamma emission probabilities per decay of ^{31}Si were taken from Ref. [3.1].

Microscopic experimental data about the ^{31}P(n,p)^{31}Si reaction excitation function are given in the works [3.2], [3.4-3.20] and cover a neutron energies range from 1.56 MeV to 14.8 MeV. The ratio of the ^{31}P(n,p)^{31}Si reaction cross section to the ^{12}C(n,2n)^{11}C reaction cross section measured by Knox [3.3] permits to evaluate the ^{31}P(n,p)^{31}Si reaction cross section at 90 MeV.

In the process of analysis the experimental data of Refs. [3.7], [3.11], [3.15-3.19] in the process of analysis were corrected to the new standards for the relevant monitor reactions (see Table 1.1) and to the recommended decay data for ^{31}Si [3.1].

Special correction was applied to the experimental data in [3.4], [3.9] and [3.14]. Experimental data by Ricamo et al. [3.4] and Cuzzocrea et al. [3.9] were renormalized to the absolute cross section of 74 mb measured by Metzger et al. [3.2] at 3 MeV. For the experimental data in [3.4] and [3.9] the correction factors were Fc = 1.39623 and Fc = 1.07246, respectively. Cross sections measured by Paulsen and Liskien [3.14] were renormalized to the results of corrected data of Ricamo et al. [3.4] in the overlapping energy range 1.91 - 2.22 MeV. The correction factor for the experimental data [3.14] is Fc = 1.88603.

The results of cross section measurement obtained by Grundl et al. at 1.59, 1.98, 2.08, 2.19, 2.57, 4.54 MeV with T(p,n)He3 neutron source [3.7] were rejected due to a significant inconsistency with experimental data in [3.4], [3.9], [3.14], [3.15]. All other results presented in the work [3.7] agree well with the main bulk of experimental data. Experimental data of Morita [3.8] were only taken into account in the evaluation for the four neutron energies: 4.85, 5.05, 5.08 and 5.22 MeV. Data of Morita obtained for the neutron energies 3.18, 3.70, 3.93, 4.23, 4.59 and 4.71 MeV were rejected due to a large underestimation of the ^{31}P(n,p)^{31}Si reaction cross section. Experimental data [3.6], [3.10], [3.12], [3.16], [3.18] and [3.20] were rejected completely.

As mentioned above, the ^{31}P(n,p)^{31}Si reaction cross section at 90 MeV may be determined from measurements of Knox [3.3]. The ratio of the ^{31}P(n,p)^{31}Si reaction cross section to the ^{12}C(n,2n)^{11}C reaction cross section, $R_{P31/C12} = (0.80 \pm 0.15)$, was measured by Knox at incident neutron energy 90 MeV.

Experimental data for the ^{12}C(n,2n)^{11}C reaction cross section at 90 MeV can only be found in an old work [3.21], $\sigma_{C12} = (22 \pm 4)$ mb. The ^{12}C(n,2n)^{11}C reaction cross section at 90 MeV may also be determined by reaction cross section ratios Mg(n,x)^{24}Na/^{12}C(n,2n)^{11}C, Si(n,x)^{24}Na/^{12}C(n,2n)^{11}C, ^{27}Al(n,x)^{24}Na/^{12}C(n,2n)^{11}C and new experimental data [3.22-3.23] for Mg(n,x)^{24}Na, Si(n,x)^{24}Na, ^{27}Al(n,x)^{24}Na reaction cross sections at 90 MeV as measured by Knox. The ^{12}C(n,2n)^{11}C reaction cross section at 90 MeV obtained as averaged-weighted value from Ref. [3.21] and above mentioned ratios are equal to (14.77 ± 1.47) mb. The usage of this value gives the ^{31}P(n,p)^{31}Si reaction cross section (11.82 ± 2.51) mb at 90 MeV.

The excitation function for the ^{31}P(n,p)^{31}Si reaction in the energy region from threshold to 60.0 MeV was evaluated by means of statistical analysis of experimental cross section data [3.2-3.5], [3.7-3.9], [3.11], [3.13-3.15], [3.17], [3.19]. The relative shape of the excitation function in the interval 12 – 30 MeV was taken from the TENDL-2011 library [3.24]. The absolute cross sections used as input data in the interval 12 – 30 MeV were calculated from TENDL-2011 data by normalization at 14.5 MeV to a value 87.70 mb which was evaluated from the representative experimental data [3.5], [3.7], [3.11], [3.13], [3.15], [3.17] and [3.19]. Additional information about the resonance structure in the ^{31}P(n,p)^{31}Si reaction excitation function has been taken from experimental data from Refs. [3.25] and [3.26] for total neutron cross sections on ^{31}P.

Statistical analysis of input cross section data was carried out by means of PADE-2 code. Rational function was used as a model function.

Uncertainties in cross sections for the evaluated ^{31}P(n,p)^{31}Si reaction excitation function are given in the form of a relative covariance matrix for 49-neutron energy groups (LB = 5). The covariance matrix of uncertainties was calculated simultaneously with the recommended cross-section data by means of the PADE-2 code and tested additionally by the COVEIG code [3.34]. The six-digit eigenvalues of the relative covariance matrix presented in File-33 are as follows:

```
5.38552E-06   5.42546E-06   5.49295E-06   5.58236E-06
5.68435E-06   5.77416E-06   5.88076E-06   5.99372E-06
6.10786E-06   6.27080E-06   6.44260E-06   6.62665E-06
6.78016E-06   6.95439E-06   7.15837E-06   7.39258E-06
7.65034E-06   7.93518E-06   8.33963E-06   9.09499E-06
9.90255E-06   1.20506E-05   1.41999E-05   1.65407E-05
1.98650E-05   2.46131E-05   3.08057E-05   3.85476E-05
4.97276E-05   7.11644E-05   1.04551E-04   1.43529E-04
2.00228E-04   2.52363E-04   2.82557E-04   3.99537E-04
5.05723E-04   5.57454E-04   5.96886E-04   6.56820E-04
7.65270E-04   1.33891E-03   2.75159E-03   3.50366E-03
5.27493E-03   1.70350E-02   2.92498E-02   1.06080E-01
1.66145E-01
```

Evaluated group cross sections and their uncertainties for the excitation function of the ^{31}P(n,p)^{31}Si reaction are listed in Table 3.1. Group boundaries are the same as in File-33.
Uncertainties for the evaluated ^{31}P(n,p)^{31}Si excitation function range from 3.44% to 38.86%. The smallest uncertainties in the evaluated cross sections 3.44 - 3.98% are observed in the neutron energy range from 4.0 to 6.75 MeV and 12.0 – 14.5 MeV. Uncertainties in cross sections exceed 10% in the energy ranges 0.732 - 1.750 and 30 - 60 MeV.

The evaluated excitation function for the ^{31}P(n,p)^{31}Si reaction in the neutron energy range from 1 MeV to 20 MeV is shown in Figs. 3.1 and 3.2 in comparison with corrected experimental data and similar data from the IRDFF-2012 and ENDF/B-VII.1 libraries. The same information for the narrower neutron energy range 1 - 6 MeV is shown in Fig. 3.3 and Fig. 3.4.

Integral experimental data for the ^{31}P(n,p)^{31}Si reaction determined in the benchmark neutron spectra are given in Refs. [3.27-3.33]. Integral cross sections presented in Refs. [3.27-3.33] were measured in neutron fields with similar spectra to the ^{235}U thermal fission neutron spectrum. Experiments in the ^{252}Cf spontaneous fission neutron spectrum are have not been carried out so far. Measured integral cross-sections for ^{235}U thermal fission neutron spectrum range from (35.12 ± 1. 38) mb [3.28] to (37.58 ± 1.19) mb [3.33]. All integral experimental data were corrected to the new standards.

D. Ricabarra et al. measured the ^{31}P(n,p)^{31}Si integral cross-section at R.A.1 reactor of CNE, Argentina [3.27]. Measurements were carried out at the core of the reactor using ^{32}S(n,p)^{32}P reaction as monitor. The obtained $^{31}P(n,p)^{31}Si$ integral cross-section is equal to $<\sigma>_{U-235}$ = (35.23 ± 2.19) mb.

The $^{31}P(n,p)^{31}Si$ spectrum averaged cross section was measured by Boldeman using the 90%-enriched ^{235}U fission plate converter facility (FPC) at Moata reactor [3.28]. The $^{32}S(n,p)^{32}P$ reaction was used as monitor. He has obtained an integral cross-section $<\sigma>_{U-235}$ = (35.12 ± 1.38) mb for the $^{31}P(n,p)^{31}Si$ reaction.

Table 3.1. Evaluated cross sections and their uncertainties for the $^{31}P(n,p)^{31}Si$ reaction in the NEUTRON energy range from threshold to 60 MeV.

Neutron energy (MeV) from to	Cross section (mb)	Uncertainty (%)	Neutron energy (MeV) from to	Cross section (mb)	Uncertainty (%)
0.732 - 1.750	1.063	38.86	8.000 - 8.500	139.678	4.54
1.750 - 2.000	14.742	5.57	8.500 - 9.000	142.234	4.59
2.000 - 2.250	26.353	4.67	9.000 - 9.500	144.596	4.57
2.250 - 2.500	42.692	4.82	9.500 - 10.000	146.764	4.49
2.500 - 2.750	70.387	4.59	10.000 - 10.500	146.383	4.38
2.750 - 3.000	76.048	4.62	10.500 - 11.000	141.454	4.26
3.000 - 3.250	99.558	4.71	11.000 - 12.000	130.045	4.10
3.250 - 3.500	83.899	4.54	12.000 - 13.000	114.530	3.97
3.500 - 3.750	112.353	4.35	13.000 - 14.000	100.328	3.94
3.750 - 4.000	111.786	4.18	14.000 - 14.500	90.699	3.98
4.000 - 4.200	97.943	3.97	14.500 - 15.000	84.705	4.04
4.200 - 4.400	120.202	3.81	15.000 - 16.000	77.301	4.18
4.400 - 4.600	128.511	3.67	16.000 - 17.000	69.160	4.46
4.600 - 4.800	138.317	3.57	17.000 - 18.000	62.205	4.82
4.800 - 5.000	130.969	3.49	18.000 - 19.000	56.225	5.23
5.000 - 5.200	119.784	3.45	19.000 - 20.000	51.116	5.66
5.200 - 5.400	129.315	3.44	20.000 - 22.500	44.104	6.36
5.400 - 5.600	134.710	3.45	22.500 - 25.000	36.552	7.27
5.600 - 6.000	131.878	3.51	25.000 - 27.500	31.081	8.06
6.000 - 6.250	139.679	3.63	27.500 - 30.000	26.966	8.82
6.250 - 6.500	143.103	3.74	30.000 - 35.000	22.992	10.07
6.500 - 6.750	140.951	3.87	35.000 - 40.000	19.786	12.13
6.750 - 7.000	136.848	4.00	40.000 - 50.000	17.119	15.52
7.000 - 7.500	135.275	4.19	50.000 - 60.000	15.172	19.88
7.500 - 8.000	137.126	4.40			

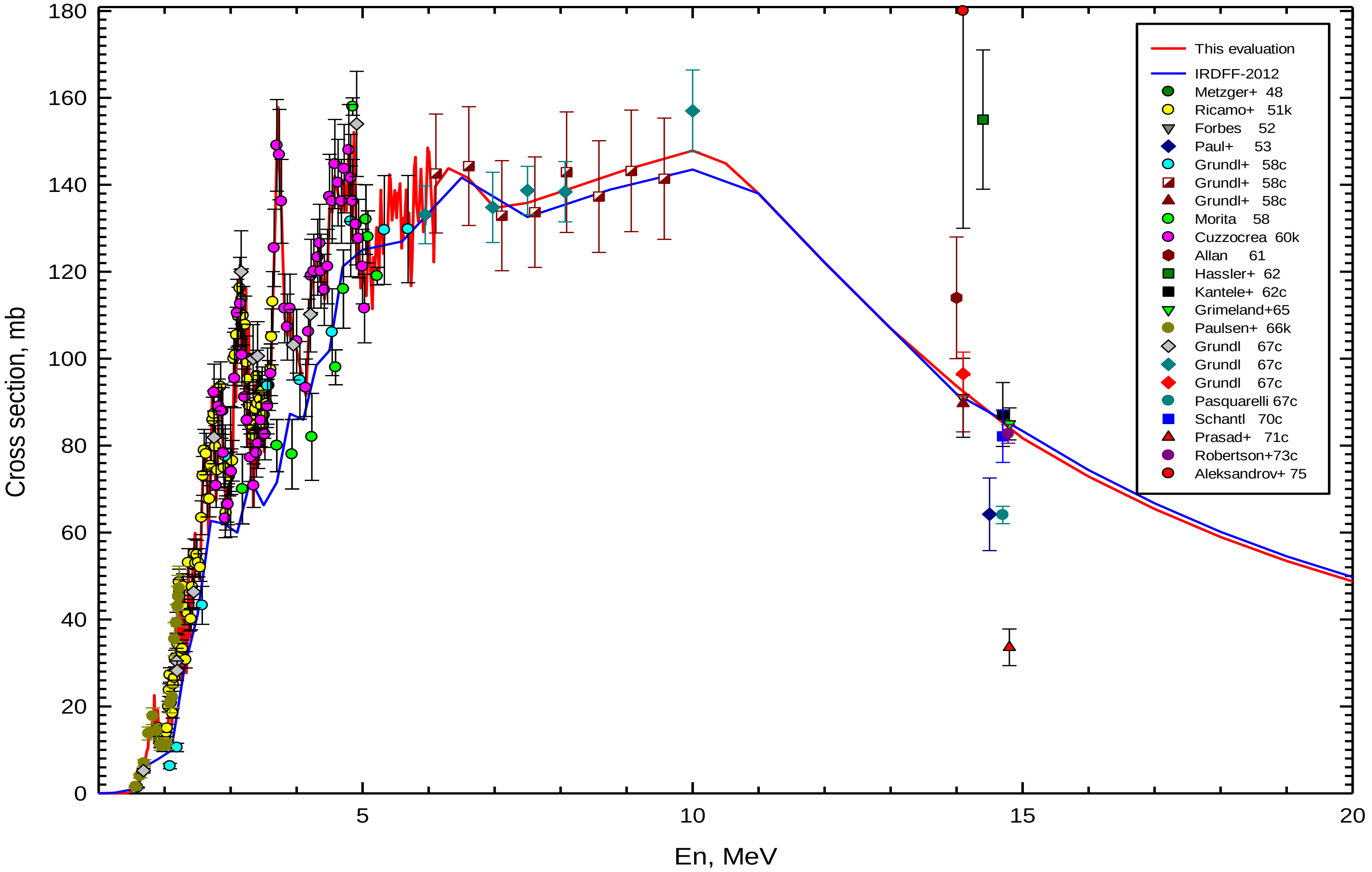

Fig. 3.1. Evaluated ^{31}P(n,p)^{31}Si reaction excitation function in the energy range 1 – 20 MeV in comparison with equivalent data from IRDFF-2012 file and corrected experimental data.

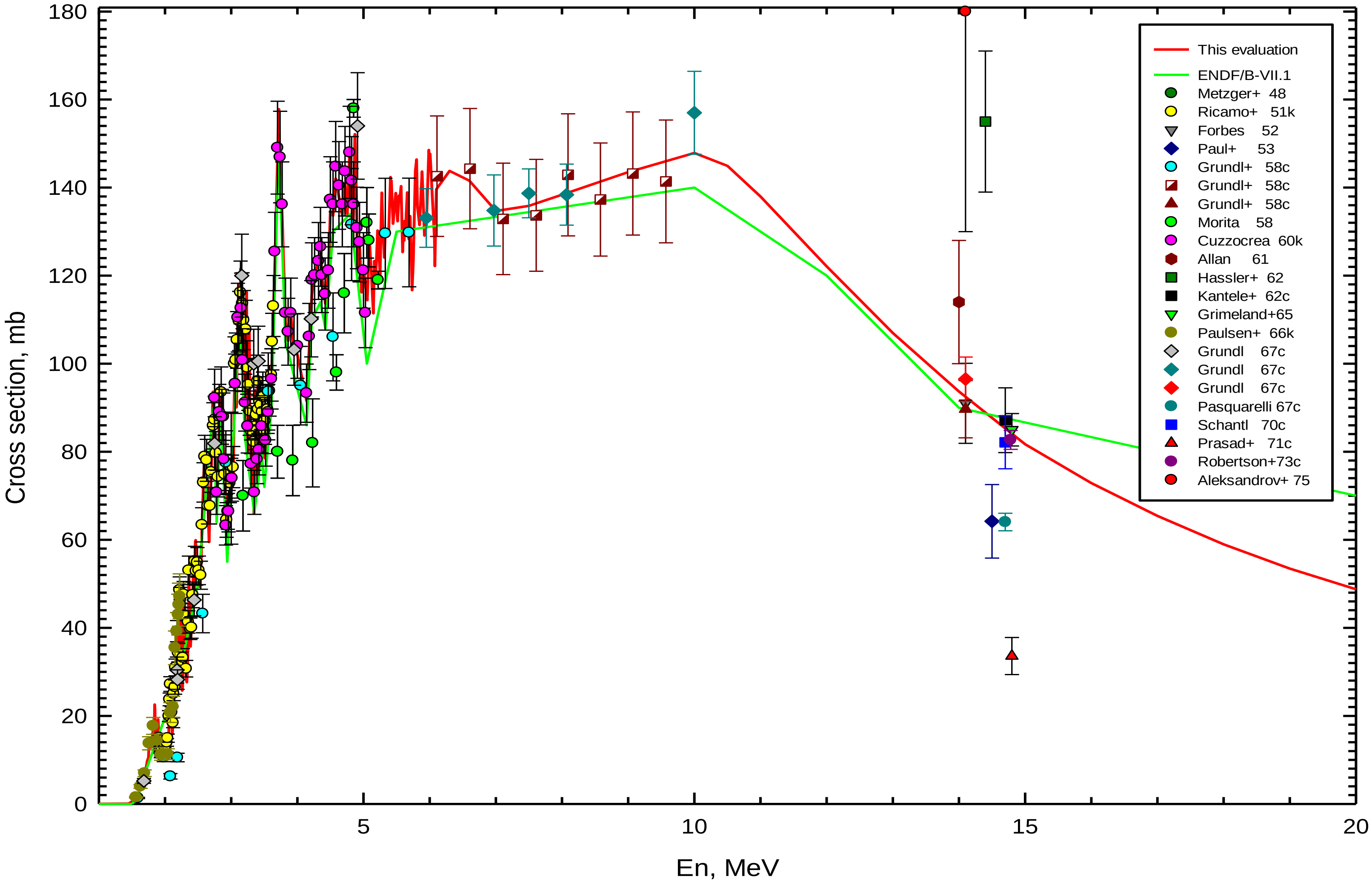

Fig. 3.2. Evaluated ^{31}P(n,p)^{31}Si reaction excitation function in the energy range 1 – 20 MeV in comparison with equivalent data from ENDF/V-II.1 library and corrected experimental data.

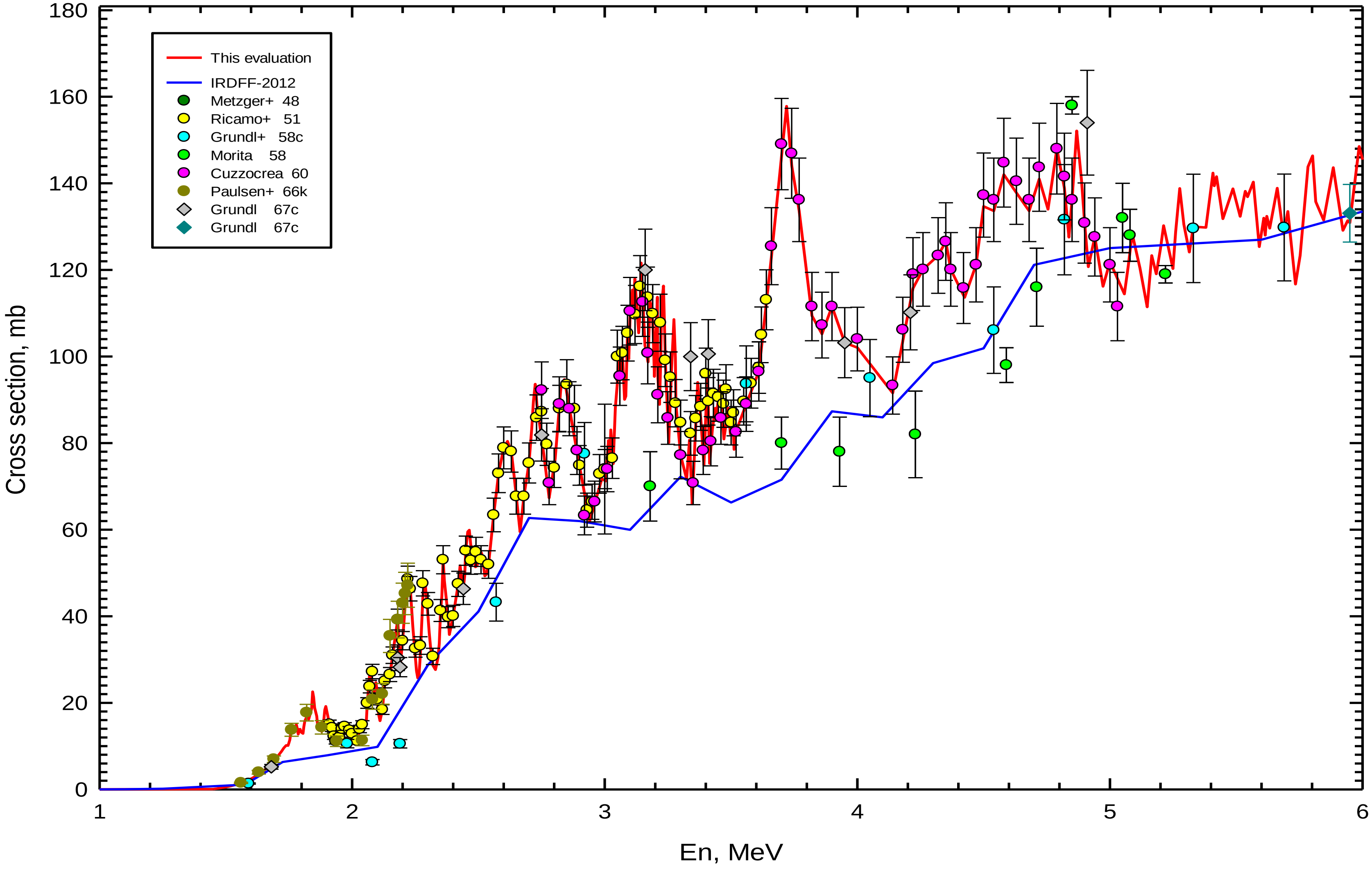

Fig. 3.3. Evaluated ^{31}P(n,p)^{31}Si reaction excitation function in the energy range 1 – 6 MeV in comparison with equivalent data from IRDFF-2012 file and corrected experimental data.

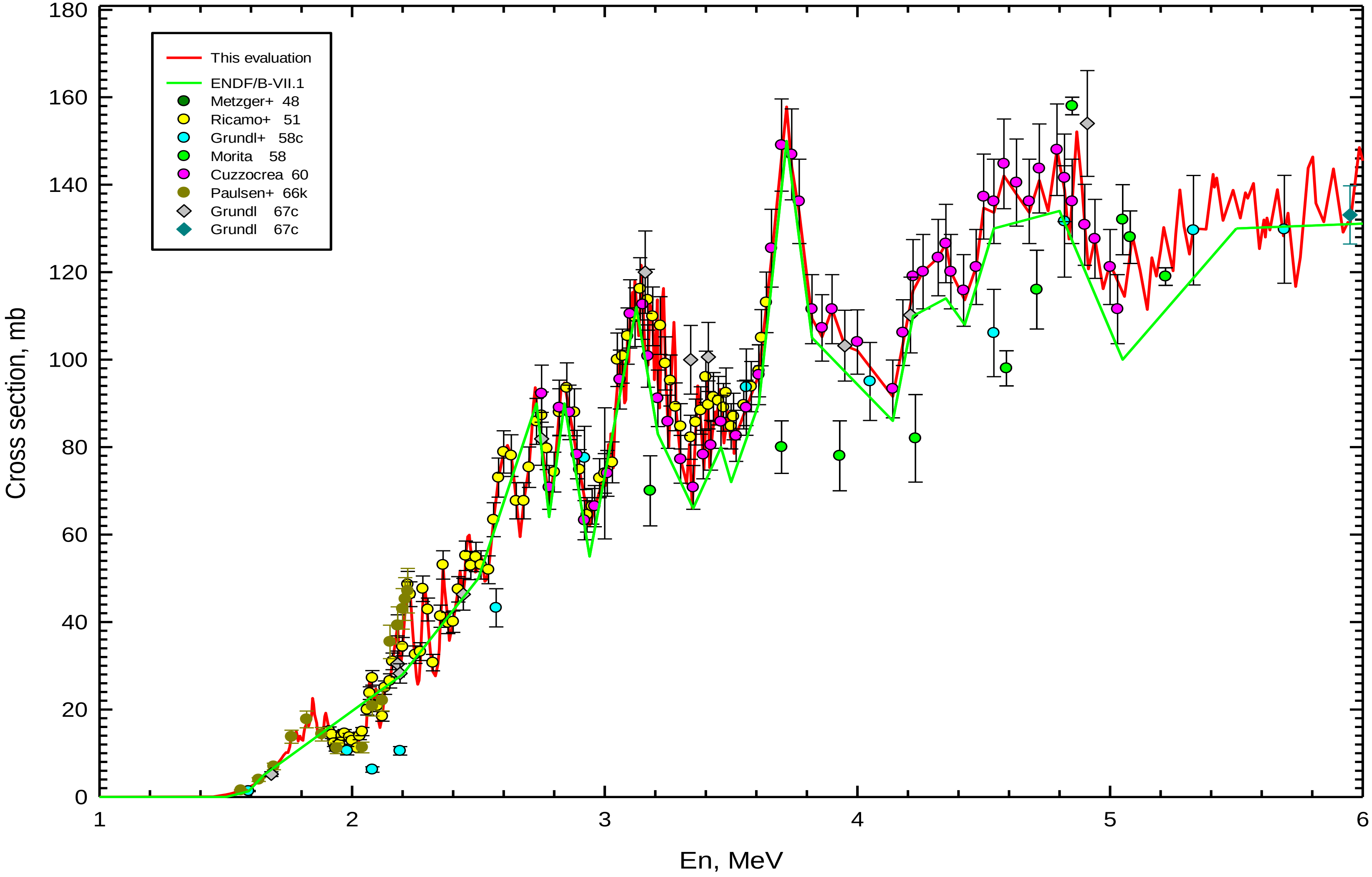

Fig. 3.4. Evaluated ^{31}P(n,p)^{31}Si reaction excitation function in the energy range 1 – 6 MeV in comparison with equivalent data from ENDF/V-II.1 library and corrected experimental data.

Grundl [3.29] carried out an experiment at a Hydro source-reactor with cavity fission-spectrum arrangement. An assembly of investigated samples placed between two ^{235}U fission plates was centered in a glass-walled spherical cavity of 10.16 cm in diameter, which was located at the center of D_2O thermal column. Grundl measured the spectral index ^{238}U(n,f)/^{31}P(n,p)^{31}Si = 8.40 ± 4.5%, that gives the ^{31}P(n,p)^{31}Si integral cross-section $<\sigma>_{U-235}$ = (36.82 ± 1.71) mb.

The results of two measurements were presented by Kobayashi and Kimura in their publication [3.30]. The first experiment was carried out at the thermal reactor KUR using the 90%-enriched ^{235}U fission plate converter facility. The measured ^{31}P(n,p)^{31}Si integral cross-section is equal to $<\sigma>_{U-235}$ = (35.98 ± 2.15) mb. The second experiment was carried out at the fast research reactor YAYOI of Tokyo University. Measurements were performed in the core centre of reactor. The ^{31}P(n,p)^{31}Si integral cross-section $<\sigma>_{U-235}$ = (36. 51 ± 2.18) mb was obtained. The neutron flux in both experiments was monitored by three dosimetry reactions: ^{27}Al(n,α)^{24}Na, ^{58}Ni(n,p)^{58}Co and ^{115}In(n,n')^{115m}In.

Geraldo, Dias and Koskinas [3.31-3.33] report the measurement of ^{31}P(n,p)^{31}Si average cross section in U-235 fission field generated in position no. 1 near the core of the IEA-R1 2 MW pool type research reactor at IPEN, Sao Paulo, Brazil. The measurement was performed relative to the ^{27}Al(n,α)^{24}Na monitor reaction and gives a value of $<\sigma>_{U-235}$ = (36.60 ± 1.28) mb [3.31]. The experimental results obtained relative to the ^{27}Al(n,α)^{24}Na, ^{54}Fe(n,p)^{54}Mn, ^{58}Ni(n,p)^{58}Co monitor reactions are $<\sigma>_{U-235}$ = (37.54 ± 1.46) mb [3.32] and $<\sigma>_{U-235}$ = (37.58 ± 1.19) mb [3.33].

The analysis of the experimental data for the ^{31}P(n,p)^{31}Si integral cross-section in U-235 thermal fission neutron spectrum shows a good agreement between all obtained values. Nevertheless the results of the reactor core measurements were not taken into account in the calculation of the average-weighted cross-section value for the ^{31}P(n,p)^{31}Si reaction. An average-weighted value obtained from FPC experimental data [3.28], [3.29] and [3.30] is equal to $<\sigma>_{U-235}$ = (35.860 ± 0.961) mb.

The evaluated excitation function for the ^{31}P(n,p)^{31}Si reaction was tested against the above mentioned representative integral experimental data. The calculated averaged cross sections over the ^{235}U thermal and ^{252}Cf spontaneous fission neutron spectra are compared with the IRDFF-2012, ENDF/B-VII.1, and experimental data in Table 3.2.

Table 3.2. Calculated and measured averaged cross sections for THE ^{31}P(n,p)^{31}Si reaction in ^{235}U thermal fission and ^{252}Cf spontaneous fission neutron spectra.

Type of neutron field	Averaged cross section, mb		90% response function, MeV	C/E
	Calculated	Measured		
^{235}U thermal fission neutron spectrum	35.553 [A] 28.362 [B] 33.529 [C]	35.860 ± 0.961 [*]	2.10 – 7.00 2.20 – 7.30 2.10 – 7.00	0.99144 0.79091 0.93500
^{252}Cf spontaneous fission neutron spectrum	38.059 [A] 30.685 [B] 35.888 [C]		2.10 – 7.40 2.30 – 7.70 2.10 – 7.40	

[A] - Present evaluation
[B] - IRDFF-2012
[C] - ENDF/B-VII.1
* - average-weighted value obtained from experimental data [3.28-3.30].

The 90% response function shows the neutron energies range where the investigated excitation function is tested in the benchmark spectrum.

The last column gives the value of C/E, which is a ratio of the calculated to experimental cross sections.

The C/E value obtained for the ^{235}U thermal fission neutron spectrum shows that the ^{31}P(n,p)^{31}Si integral cross sections calculated from newly evaluated excitation function agree well with the relevant experimental data. The $<\sigma>_{U\text{-}235}$ cross sections calculated from the RRDFF-2012 and ENDF/B-VII.1 excitation functions agree worse with the relevant experimental value. Discrepancies between the calculated and experimental values for these libraries exceed the experimental uncertainties.

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4. EVALUATION OF THE EXCITATION FUNCTION OF THE ^{113}IN(N,Γ)^{114M}IN REACTION

The natural indium consists of two isotopes: ^{113}In with abundance (4.29 ± 0.05) atom percent and ^{115}In with abundance of (95.71 ± 0.05) atom percent.

Indium-114 produced by the (n,γ) reaction in ground state (^{114g}In) has the half-life equal to $T_{1/2}$= (71.9 ± 0.1) seconds, spin and parity J_{π}=1+ . ^{114g}In disintegrates via two decay modes. The (99.50 ± 0.15) % of disintegration occurs via β^- decay. The rest (0.50 ± 0.15) % of disintegration occurs via ε–capture. The β^- transition is accompanied by an emission of 223.80 and 778.72 keV β^- particles and gamma-rays with an energy of 1299.83 keV. Intensities of above mentioned β^- particles are equal to $I_{\beta 1}$ = (0.140 ± 0.020)% and $I_{\beta 2}$ = (99.36 ± 0.16)%. The intensity of 1299.83 keV gammas is very low and equal to I_{γ} = 0.139%. The X- and gamma-ray radiations accompanying ε–capture have very low intensities. This is the reason why the ^{113}In(n,γ)^{114g}In reaction rate is usually measured by the beta-spectrometry method. Typically, the number of pulses from beta-particles with average energy (777.9 ± 1.8) keV and total intensity (99.50 ± 0.16)% were measured.

Indium-114 produced in radiative neutron capture in a metastable state (^{114m}In) has the half-life $T_{1/2}$= (49.51 ± 0.01) days. The 190.2682-keV metastable level has the spin and parity of J^{π} = 5+. The decay of metastable ^{114m}In occurs via two modes. The isomeric transition (IT) to the ground state proceeds with probability (96.75 ± 0.24)%, whereas the ε–capture occurs with probability (3.25 ± 0.24)%. Isomeric transition is accompanied by emission of 190.27-keV gamma-rays with intensity I_{γ} = (15.56 ± 0.15) %. In addition to gamma-ray radiation, the IT decay is followed by the six lines spectrum of X-rays. The most intensive are the X-ray lines with energies 24.002 keV (kα2) and 24.21 keV (kα1) and intensities $I_{k\alpha 2}$= (9.8± 0.3)% and $I_{k\alpha 1}$= (18.2± 0.6)%. The X-ray and gamma-ray radiation which accompany ε–capture have a very low intensity. The ^{113}In(n,γ)^{114m}In reaction rate is measured usually by the gamma-spectrometry method. The measured value is the number of pulses in the peak of full absorption of the 190.27 keV gammas.

In the process of analysis of experimental data for neutron radiative capture on the minor isotope of indium it is necessary to take into account that indium-114 has the second isomeric level (^{114m2}In). The half-life of these level is (43.1 ± 0.6) milliseconds. The second isomeric level has an energy of 501.948 keV, the spin and parity of J^{π} = 8^-. Decay of the 501.948-keV metastable level occurs with 100% probability by IT transition to the first 190.2682-keV isomeric level. The IT transition is accompanied by 190.27-keV and 311.65-keV gamma radiation with intensities I_{γ} = (15.56 ± 0.15)% and I_{γ} = (89.85 ± 0.24)%, respectively. The IT transition is also accompanied by X-ray radiation. The most intensive X-rays are 24.002 keV (kα2) and 24.21 keV (kα1) lines. The emission intensities of these X-rays are $I_{k\alpha 2}$ = (11.9 ± 0.4)%, $I_{k\alpha 1}$ = (22.0 ± 0.7)%.

Recommended decay data for the half-life and radiation emission probabilities per decay of ^{114g}In, ^{114m1}In and ^{114m2}In were taken from Ref. [4.1].

Microscopic experimental data [4.2-4.16] were analysed in order to evaluate the radiative capture cross section for the ^{113}In, isomeric ratios $R_g(E) = \sigma_g(E)/\sigma_{m+g}(E)$, $R_m(E) = \sigma_m(E)/\sigma_{m+g}(E)$ and the ^{113}In(n,γ)^{114g}In and ^{113}In(n,γ)^{114m}In partial reaction excitation functions in a wide energy region of 1.000E-05 eV – 20 MeV. The ^{113}In(n,γ) integral experimental data for ^{235}U thermal fission and ^{252}Cf spontaneous fission neutron spectra are not available up to today.

In the first step of evaluation the experimental data for the ^{113}In(n,γ)^{114g}In, ^{113}In(n,γ)^{114m}In, ^{113}In(n,γ)$^{114m+g}$In reaction excitation functions were corrected to the new standards for monitor reactions ^{59}Co(n,γ)^{60}Co, ^{115}In(n,n')^{115m}In, ^{115}In(n,γ) ^{116m}In, ^{127}I(n,γ)^{128}I, ^{197}Au(n,γ)^{198}Au and ^{238}U(n,f) (see Table 1.1 in section 1).

The ^{113}In(n,γ)^{114m}In reaction cross sections measured by the gamma-spectrometry method were corrected for new recommended gamma intensity value I_γ = (15.56 ± 0.15)% for 190.27 keV gamma line [4.1]. In the earlier measurements the intensity for the 190.27 keV gamma line were taken between I_γ = (17.9 – 18.0)%. For example, H.A. Grench and H.O. Menlove used intensity I_γ = (17.9 ± 0.3) % for the 190.27 keV gammas [4.9] in his measurements of the ^{113}In(n,γ)^{114m}In reaction cross section in the neutron energies interval 0.36 – 1.02 MeV. The authors of later works [4.14-4.16] also used the overestimated intensity values for 190.27 keV gamma line. Trofimov used a value of I_γ = (16.7 ± 0.3)% in his measurement of the ^{113}In(n,γ)^{114m}In cross sections at 1 MeV [4.14] and 2 MeV [4.15]. A.G. Belov et al., in measurements carried out at 0.0253 eV, took a value of I_γ = 18% [4.16] for 190.27 keV radiation.

The neutron capture cross sections for the minor indium isotope were measured in Refs. [4.4], [4.6], [4.13] relative to monitor reaction ^{127}I(n,γ)^{128}I. The cross section data for the ^{127}I(n,γ)^{128}I reaction were taken from the new re-evaluation carried out in the energy range 4 keV - 6 MeV (see Ref. [1.11] in section 1).

The experimental data for radiative capture cross section for indium-113 at the thermal energy are given in Refs. [4.2-4.3], [4.5], [4.8], [4.10-4.12] and [4.16]. The more representative are results of measurements obtained by Keish [4.5]. The ^{113}In(n,γ)^{114g}In and ^{113}In(n,γ)^{114m}In thermal cross sections presented in Ref. [4.5] was measured using indium samples with a 96% content of isotope ^{113}In. Keish has carefully carried out his measurements of activity accompanying decay of ^{114g}In and ^{114m}In. The absolute efficiency of β-counter was determined using the ^{188}Re source, which emits the β-particles with the same energy as indium-114. S.F. Mughabghab recommended the ^{113}In(n,γ)^{114g}In, ^{113}In(n,γ)^{114m}In and ^{113}In(n,γ)$^{114m+g}$In reaction cross sections at 0.0253 eV point: (3.9 ± 0.4), (8.1 ± 0.8) and (12.0 ± 1.1) barn, respectively [4.17], which were evaluated on the basis of experimental data of Keish. These data were adopted as standard radiative capture cross sections for indium-113 at the neutron energy 0.0253 eV.

Reich-Muir resonance parameters were used to obtain the ^{113}In(n,tot), ^{113}In(n,el) and ^{113}In(n,γ) reaction cross sections in the neutron energy range 1.000E-05 eV – 2.619 keV. The resolved resonance parameters given in the compilation of S.F. Mughabghab [4.17] were used as zero approximation.

In the process of evaluation of resolved resonance parameters the experimental data of Refs. [4.18-4.22] presented in the EXFOR library were analysed. The measurements carried out at the isotope ^{113}In give information about resonances with energies from 1.82 eV to 1.996 keV. All resonances determined in the experiments, were identified by authors as resonances of s–wave (neutron orbital moment L = 0).

The most problematical question concerns the evaluation parameters of the first lowest resonance, excited in the n + ^{113}In interaction. Compilation [4.17] gives for the first s-resonance the following parameters: energy of resonance - E_r = 1.800 eV, spin of resonance – J = 4, neutron width - Γ_n = 2.722222E-4 eV, radiative width - Γ_γ = 7.800000E-2 eV. Information about the source of these parameters is not detailed by S.F. Mughabghab. The one single work, that has deduced the experimental data for parameters of the first 1.8 eV resonance, is the publication of Anufriev et al. [4.21]. The measurements, performed by the TOF method at the horizontal beam of reactor SM-2 (NIIAR, Dimitrovgrad). The flight path was equal to 91.7 meters, the time resolution - 58 nsec/m. In this experiment [4.21], the total Γ_t and neutron $2g\Gamma_n$ widths of 1.82 eV, 4.72 eV, 14.75 eV, 21.65 eV, 25.11 eV and 32.34 eV resonances were measured. The energies of resonances E_r are left the same as received by the authors. Parameters for the 1.82 eV resonance have been obtained from experimental data for the total cross section of the irradiated Sn sample. If a spin of the first resonance is J = 4, the rest parameters obtained from experimental data [4.21] will be following: E_r = 1.82 ± 0.01 eV, neutron width Γ_n= (1.77778 ± 0.77778)E-4 eV, radiative width Γ_γ = (8.18222 ± 0.00608)E-2 eV. Calculations, carried out with these parameters for the first resonance show bad agreement with cross sections at 0.0253 eV recommended in compilation [4.17].

In the new data file for ^{113}In the following parameters were taken for the first s–resonance: energy of the resonance E_r = 1.805 eV, spin J = 4, neutron width Γ_n = 2.722222E-4 eV, radiative width Γ_γ = 7.800000E-2 eV. A small increase in the energy of resonance permits to improve the agreement between reconstructed and recommended cross sections at the thermal point 0.0253 eV.

In the process of analysis of experimental data, the energies of the 2-nd, 3-rd and 7-th s-resonance were determined more precisely: 4.713 ± 0.016 eV, 14.700 ± 0.026 eV and 32.250 ± 0.019 eV, respectively.

Weak neutron resonances with Γ_n = (3.636364E-4 - 1.230769E-6) eV, observed in experiment in the interval 30.86 - 200.6 eV, were identified as p-wave resonances.

Parameters of resonances exited by p-neutrons (L = 1) above 200.6 eV and d-neutrons (L = 2) in the interval 1.109639 – 2.689350 keV were taken from the evaluation of A.J. Koning and D. Rochman. They developed a method of generation the resonance parameters for neutrons with L = 0 - 2. Generation of resonance parameters was carried out by means of the TARES-1.1 code and the data base ”Radiator” created for this code [4.23].

The energy resolution of the existing experimental technique does not permit to determine the parameters of d–resonances. Inclusion of the data for d–wave neutrons permits to extend the upper boundary of the resolved resonance region (RRR). It should be noted that parameters Γ_γ assigned to p-resonances in the TENDL-2012 library in the energy interval 30.86 - 200.6 eV are significantly overestimated. In the described new evaluation the parameters for p-resonances in the energy interval 30.86 - 200.6 eV were determined from the analysis of experimental data.

Regrettably, the experimental data for the ^{113}In(n,tot), ^{113}In(n,el) and ^{113}In(n,γ) reactions cross section in the resolved resonance region are not available up to today. Hence the evaluated resonance parameters could only be tested at the 0.0253 eV point. Reconstructed from evaluated resonance parameters, the ^{113}In(n,el) and ^{113}In(n,γ) cross sections at 0.0253 eV at the temperature 300K are equal to 3.68624 and 12.0482 barn, respectively. Cross section values recommended by S.F. Mughabghab are equal to (3.67 ± 0.08) and (12.0 ± 1.1) barn, respectively [4.17]. The cross section of elastic scattering on a free ^{113}In atom (3.75±0.07) barn, measured by Koester and Knopf at 0.51E-03 eV [4.24], supports the recommendation of S.F. Mughabghab.

The ^{113}In(n,el) and ^{113}In(n,γ) cross sections, reconstructed from the evaluated TENDL-2012 resonance parameters at 0.0253 eV and temperature 300K, are equal to 3.2717 barn and 12.1317 barn, respectively.

In the process of the evaluation of the ^{113}In resonance parameters two important characteristics were also tested: a value of Westcott parameter (g-factor) and a value of radiative capture resonance integral ($I_{r\gamma}$). The values recommended by S.F. Mughabghab are the following: g-factor=1.0057, $I_{r\gamma}$= (320±30) barn.

The new data file for indium-113 contains information for 684 resonances. In the framework of the Reich-Muir formalism the parameters for 387 s-resonances were determined: 97 p-resonances and 200 d-resonances. As mentioned above, RRR region covers the neutron energies range 1.000E-05 eV – 2.619 keV.

For determination of the ^{113}In(n,γ)^{114g}In and ^{113}In(n,γ)^{114m}In reaction excitation functions in the energy range 1.000E-05 eV – 20 MeV, the cross-section ratios $\sigma_g(E)/\sigma_{m+g}(E)$ and $\sigma_m(E)/\sigma_{m+g}(E)$ have been evaluated. The evaluation was carried out on the basis of the recommended data of Mughabghab at the 0.0253 eV point [4.17] and experimental data from works [4.7] and [4.9]. The evaluated cross-section ratios $\sigma_g(E)/\sigma_{m+g}(E)$ and $\sigma_m(E)/\sigma_{m+g}(E)$ are shown in Fig. 4.1 and Fig. 4.2 in comparison with experimental data and equivalent data from the EAF-2010, ROSFOND-2010 and TENDL-2012 libraries. The ratios $\sigma_g(E)/\sigma_{m+g}(E)$ and $\sigma_m(E)/\sigma_{m+g}(E)$ displayed in Fig. 4.1 and Fig.4.2 show that results of the new evaluation agree better with experimental data than equivalent data from the EAF-2010, ROSFOND-2010, TENDL-2012 libraries.

The evaluated ratios $R_1(E) = \sigma_g(E)/\sigma_{m+g}(E)$ and $R_2(E) = \sigma_m(E)/\sigma_{m+g}(E)$ at 22 points in the interval 1.000E-05 eV - 20 MeV are given in the data file for indium-113. In accordance with the ENDF/B format the ratios are given in the MF = 9 file in the order of increasing level energy for $R_1(E)$ and $R_2(E)$. In the ROSFOND-2010 library, $R_1(E)$ и $R_2(E)$ are given in the reverse order.

Experimental data for the ^{113}In(n,γ)^{114g}In reaction excitation function are obtained for incident neutron energies 7.8 keV - 1 MeV. The ^{113}In(n,γ)^{114m}In reaction cross section has been measured in the energy interval 7.8 keV - 2 MeV. The ^{113}In(n,γ)$^{114m+g}$In reaction cross section was not measured directly. Total radiative capture cross section for ^{113}In may be determined by summing up the partial cross sections.

In the evaluation the ^{113}In(n,γ)^{114g}In, ^{113}In(n,γ)^{114m}In and ^{113}In(n,γ)$^{114m+g}$In reaction excitation functions in the interval of 2.619–7.8 keV and above 2 MeV, those data were dominant which had been obtained from theoretical model calculation carried out by means of the modified version of the GNASH code, which is a significantly improved version of the original GNASH code.

The modified GNASH code as mentioned in Section 1 includes subroutine, which permits to take into account the neutron width fluctuation. Furthermore, the modified GNASH code has a mode which permits to calculate cross-section of population of individual levels excited in the investigated reaction. This capability is very important to calculate the ^{113}In(n,γ)^{114g}In and ^{113}In(n,γ)^{114m}In reaction cross sections. The neutron optical parameters were calculated by means of the ECIS code.

The excitation function of the ^{113}In(n,γ)^{114m}In reaction in the energy range from 2.619 keV to 20 MeV was evaluated by means of statistical analyses of the experimental cross-section data [4.4], [4.7], [4.9], [4.13-4.15] and data from theoretical model calculation, which were used as additional source of information between 2.619–7.8 keV and 2 - 20 MeV.

Uncertainties in the evaluated ^{113}In(n,γ)^{114m}In reaction excitation function are given as two independent matrixes.

In the RRR range 1.0E-5 eV – 2.619 keV uncertainties are given in the form of diagonal matrix for the 37 neutron energy intervals (LB = 1). Uncertainties in cross sections were calculated by means of the DSIGNG code [4.25] from uncertainties in Reich-Muir resonance parameters. In the energy range 2.619 keV - 20 MeV the uncertainties are presented in the form of relative covariance matrix for the 49-neutron energy groups (LB = 5). Covariance matrix was generated by the PADE-2 code simultaneously with cross sections. All eigenvalues of the relative covariance matrix presented in the sub file-40 in six-digit representation are positive:

```
1.38469E-09   2.09464E-09      2.69099E-09      3.43341E-09
4.11168E-09   5.99906E-09      9.93656E-09      1.54654E-08
2.14259E-08   2.75352E-08      4.02100E-08      6.61675E-08
7.02494E-08   7.51831E-08      8.45538E-08      9.25912E-08
9.61765E-08   1.00756E-07      1.04351E-07      1.06704E-07
1.78985E-07   6.34161E-07      2.41733E-06      7.63306E-06
3.16510E-05   1.35632E-04      1.72482E-04      5.15391E-04
5.95402E-04   7.00698E-04      7.95169E-04      8.44792E-04
9.23952E-04   1.43073E-03      2.11018E-03      3.10634E-03
4.79421E-03   5.46918E-03      6.57118E-03      7.93899E-03
9.36067E-03   1.12490E-02      1.26068E-02      1.48601E-02
1.55817E-02   1.75117E-02      2.24708E-02      3.63558E-02
2.52709E-01
```

A test carried out by means of the COVEIG code [4.26] has also shown that all eigenvalues in LB = 5 sub-matrix are positive.

The evaluated group cross sections and related uncertainties for the ^{113}In(n,γ)^{114m}In reaction excitation function are listed in Table 4.1. Group boundaries are the same as in File-40.

The lowest uncertainties in the evaluated cross sections 2.90 - 3.43% are observed in the neutron energy range from 2.619 keV to 1.20 MeV. In the resolved resonance region (RRR) the minimal uncertainty of 4.75% is observed in the interval 160 - 180 eV. In other regions of RRR, the uncertainty in cross sections is equal to 8.29 - 26.83%. Above 1.20 MeV, the uncertainty in cross sections increases and reaches maximum value of 23.06% at the interval 18 - 20 MeV. This can be explained by the fact that all information about excitation function above 2 MeV was obtained from one source – theoretical model calculation carried out with the GNASH code.

The evaluated ^{113}In(n,γ)^{114m}In reaction excitation function in the energy range 1.0E-8 – 0.001 MeV and 0.001 – 20 MeV is shown in Fig 4.3 and Fig 4.4, respectively. In both Figs., the equivalent data from the TENDL-2012, EAF-2010, ROSFOND-2010 libraries and corrected experimental data are presented for comparison. The ^{113}In(n,γ)^{114m}In reaction cross section evaluated in this work in the neutron energies range 1.000E-05 eV – 2.619 keV was obtained from evaluated resonance parameters with following correction for the evaluated isomeric ratio $\sigma_m(E)/\sigma_{m+g}(E)$. In Fig 4.3 at the energies range 2.619 keV – 20 MeV are shown results of the statistical analysis of cross sections from described above data base. All evaluated data are given in the SAND-II 640-groups representation.

As can be seen in Fig. 4.3, the ^{113}In(n,γ)^{114m}In reaction excitation function evaluated in this work agrees well with cross section (8.1 ± 0.8) barn at 0.0253 eV, recommended by S.F. Mughabghab [4.17]. The same may be said about equivalent cross section data from the ROSFOND-2010 library. The ^{113}In(n,γ)^{114m}In reaction cross section at 0.0253 eV in the TENDL-2012 library is significantly overestimated, while it is underestimated by about 14% in the EAF-2010 library.

The systematic overestimation of the ^{113}In(n,γ)^{114m}In reaction excitation function in the TENDL-2012 library takes place at neutron energies from 1.000E-05 eV to 50 keV keV. In the EAF-2010 library the ^{113}In(n,γ)^{114m}In reaction cross section is systematically underestimated in the energy intervals 1.000E-11 – 3.5E-04 MeV and 4.5E-04 – 2.0 MeV.

Table 4.1. Evaluated cross sections and their uncertainties for the ^{113}In(n,γ)^{114m}In reaction in the NEUTRON energy range from 1.000E-5 eV to 20 MeV.

Neutron energy (eV) from to	Cross section (barns)	Uncertainty (%)	Neutron energy (eV) from to	Cross section (barns)	Uncertainty (%)
1.000E-05 - 1.000E-04	1.93279E+2	9.20	9.000E+03 - 1.000E+04	1.18748E+0	3.11
1.000E-04 - 1.000E-03	6.11499E+1	9.20	1.000E+04 - 1.500E+04	1.04901E+0	3.16
1.000E-03 - 1.000E-02	1.94226E+1	9.21	1.500E+04 - 2.000E+04	8.96599E-1	3.11
1.000E-02 - 2.000E-02	1.06871E+1	9.22	2.000E+04 - 3.000E+04	7.64868E-1	3.01
2.000E-02 - 3.000E-02	8.27662E+0	9.23	3.000E+04 - 4.000E+04	6.63651E-1	3.24
3.000E-02 - 5.600E-02	6.47766E+0	9.27	4.000E+04 - 5.000E+04	6.06636E-1	3.53
5.600E-02 - 1.000E-01	4.95379E+0	9.32	5.000E+04 - 6.000E+04	5.64331E-1	3.46
1.000E-01 - 3.000E-01	3.55683E+0	9.49	6.000E+04 - 7.000E+04	5.22339E-1	3.49
3.000E-01 - 5.600E-01	3.09180E+0	9.86	7.000E+04 - 8.000E+04	4.80347E-1	3.48
5.600E-01 - 1.000E+00	3.97000E+0	10.48	8.000E+04 - 9.000E+04	4.40683E-1	3.38
1.000E+00 - 1.500E+00	1.17728E+1	11.23	9.000E+04 - 1.000E+05	4.09025E-1	3.36
1.500E+00 - 2.000E+00	3.41334E+2	14.86	1.000E+05 - 1.500E+05	3.47778E-1	3.29
2.000E+00 - 3.000E+00	9.68776E+0	11.18	1.500E+05 - 2.000E+05	2.88829E-1	3.18
3.000E+00 - 4.000E+00	1.24266E+0	8.29	2.000E+05 - 3.000E+05	2.48695E-1	3.02
4.000E+00 - 5.000E+00	3.30428E+1	16.98	3.000E+05 - 4.000E+05	2.26011E-1	2.90
5.000E+00 - 6.000E+00	1.37662E+0	11.19	4.000E+05 - 5.000E+05	2.16821E-1	2.93
6.000E+00 - 8.000E+00	3.81349E-1	11.41	5.000E+05 - 6.000E+05	2.17539E-1	3.03
8.000E+00 - 1.000E+01	4.06627E-1	16.55	6.000E+05 - 7.000E+05	2.22268E-1	3.13
1.000E+01 - 1.600E+01	1.05004E+2	30.32	7.000E+05 - 8.000E+05	2.28838E-1	3.19
1.600E+01 - 2.500E+01	4.75664E+1	9.06	8.000E+05 - 1.000E+06	2.42178E-1	3.21
2.500E+01 - 4.000E+01	3.89342E+1	12.85	1.000E+06 - 1.200E+06	2.59974E-1	3.43
4.000E+01 - 6.300E+01	5.91964E+0	12.34	1.200E+06 - 1.400E+06	2.70419E-1	4.22
6.300E+01 - 1.000E+02	1.57415E+1	9.94	1.400E+06 - 1.600E+06	2.62624E-1	5.35
1.000E+02 - 1.275E+02	1.55815E+1	9.49	1.600E+06 - 1.800E+06	2.37882E-1	6.40
1.275E+02 - 1.600E+02	1.75649E+0	17.64	1.800E+06 - 2.000E+06	2.02044E-1	7.19
1.600E+02 - 1.800E+02	9.59548E-3	4.75	2.000E+06 - 2.500E+06	1.39866E-1	8.10
1.800E+02 - 2.000E+02	3.34291E-1	39.42	2.500E+06 - 3.000E+06	7.72814E-2	9.46
2.000E+02 - 2.350E+02	1.14217E+1	16.45	3.000E+06 - 3.500E+06	4.42908E-2	10.51
2.350E+02 - 2.650E+02	4.79178E+0	18.53	3.500E+06 - 4.000E+06	2.70755E-2	11.25
2.650E+02 - 3.150E+02	2.61858E+0	18.76	4.000E+06 - 5.000E+06	1.45459E-2	11.90
3.150E+02 - 4.000E+02	6.56412E-1	23.74	5.000E+06 - 6.000E+06	6.85625E-3	12.58
4.000E+02 - 5.250E+02	1.73558E+0	20.13	6.000E+06 - 7.000E+06	3.47385E-3	13.32
5.250E+02 - 7.200E+02	5.91258E+0	20.94	7.000E+06 - 8.000E+06	1.81447E-3	14.45
7.200E+02 - 1.000E+03	6.07129E+0	26.21	8.000E+06 - 9.000E+06	9.96093E-4	16.05
1.000E+03 - 1.400E+03	3.69763E+0	26.90	9.000E+06 - 1.000E+07	6.63539E-4	17.34
1.400E+03 - 1.950E+03	2.98317E+0	26.69	1.000E+07 - 1.100E+07	6.49130E-4	16.56
1.950E+03 - 2.619E+03	2.55561E+0	26.83	1.100E+07 - 1.200E+07	8.01033E-4	15.77
2.619E+03 - 3.000E+03	2.11843E+0	3.10	1.200E+07 - 1.300E+07	9.70856E-4	15.46
3.000E+03 - 4.000E+03	1.90232E+0	3.10	1.300E+07 - 1.400E+07	1.03816E-3	14.81
4.000E+03 - 5.000E+03	1.68853E+0	3.13	1.400E+07 - 1.500E+07	9.76878E-4	14.55
5.000E+03 - 6.000E+03	1.54023E+0	3.10	1.500E+07 - 1.600E+07	8.46062E-4	15.05
6.000E+03 - 8.000E+03	1.36987E+0	3.07	1.600E+07 - 1.800E+07	6.21981E-4	16.89
8.000E+03 - 9.000E+03	1.24633E+0	3.09	1.800E+07 - 2.000E+07	3.62934E-4	23.06

The absolute values of neutron radiative capture cross section for ^{113}In at energy range 2.619 keV – 20 MeV were obtained from two evaluated functions: the ^{113}In(n,γ)^{114m}In reaction excitation function and isomeric ratio $\sigma_m(E)/\sigma_{m+g}(E)$. The ^{113}In(n,γ)^{114g}In reaction cross section for the energy range 2.619 keV – 20 MeV was determined on the basis of the total capture cross section and evaluated ratio $\sigma_g(E)/\sigma_{m+g}(E)$.

The ^{113}In(n,γ)^{114g}In reaction excitation function evaluated by means of the described method is shown in Fig. 4.5 and Fig. 4.6 in the neutron energy range of 1.0E-8 – 0.001 MeV and 0.001 – 20 MeV, respectively. For comparison, the both Figs. display the corresponding data from the TENDL-2012, EAF-2010, ROSFOND-2010 libraries and corrected experimental data. The ^{113}In(n,γ)^{114g}In reaction excitation function evaluated in this work agrees well with cross section (3.9 ± 0.4) barn at 0.0253 eV recommended by S.F. Mughabghab [4.17]. This is also true for equivalent cross section data from ROSFOND-2010 library. The ^{113}In(n,γ)^{114g}In reaction cross section at 0.0253 eV in the TENDL-2012 library is significantly underestimated while it is overestimated by about 14% in the EAF-2010 library. The ^{113}In(n,γ)^{114g}In cross section measured by W. Poenitz at 64 keV [4.7] contradicts all evaluations results.

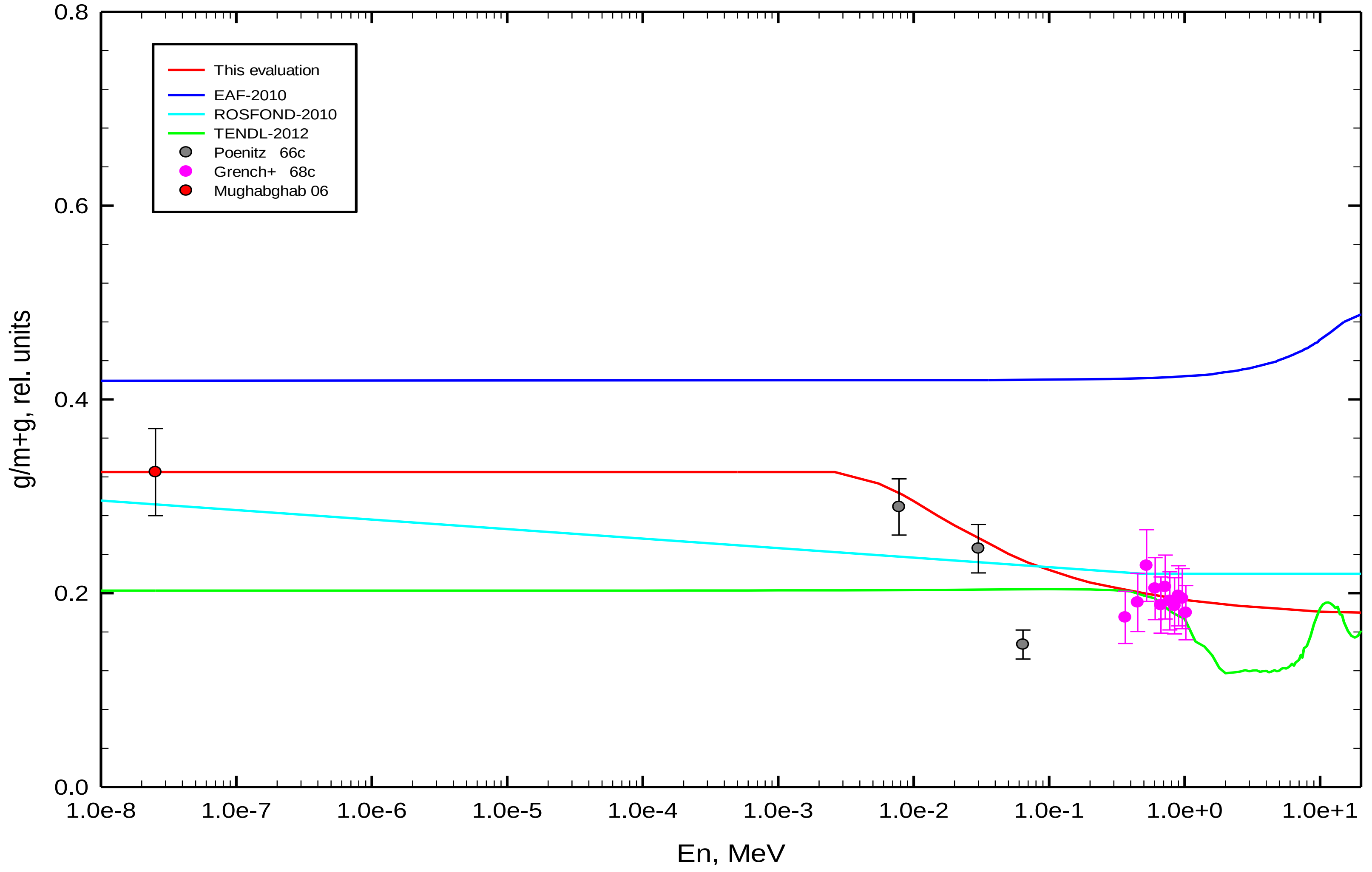

Fig. 4.1. Evaluated cross section ratio of the reactions $^{113}In(n,\gamma)^{114g}In$ and $^{113}In(n,\gamma)^{114m+g}In$ in the energy range (1.0E-8 – 20) MeV in comparison with equivalent data from EAF-2010, ROSFOND-2010, TENDL-2012 and experimental data.

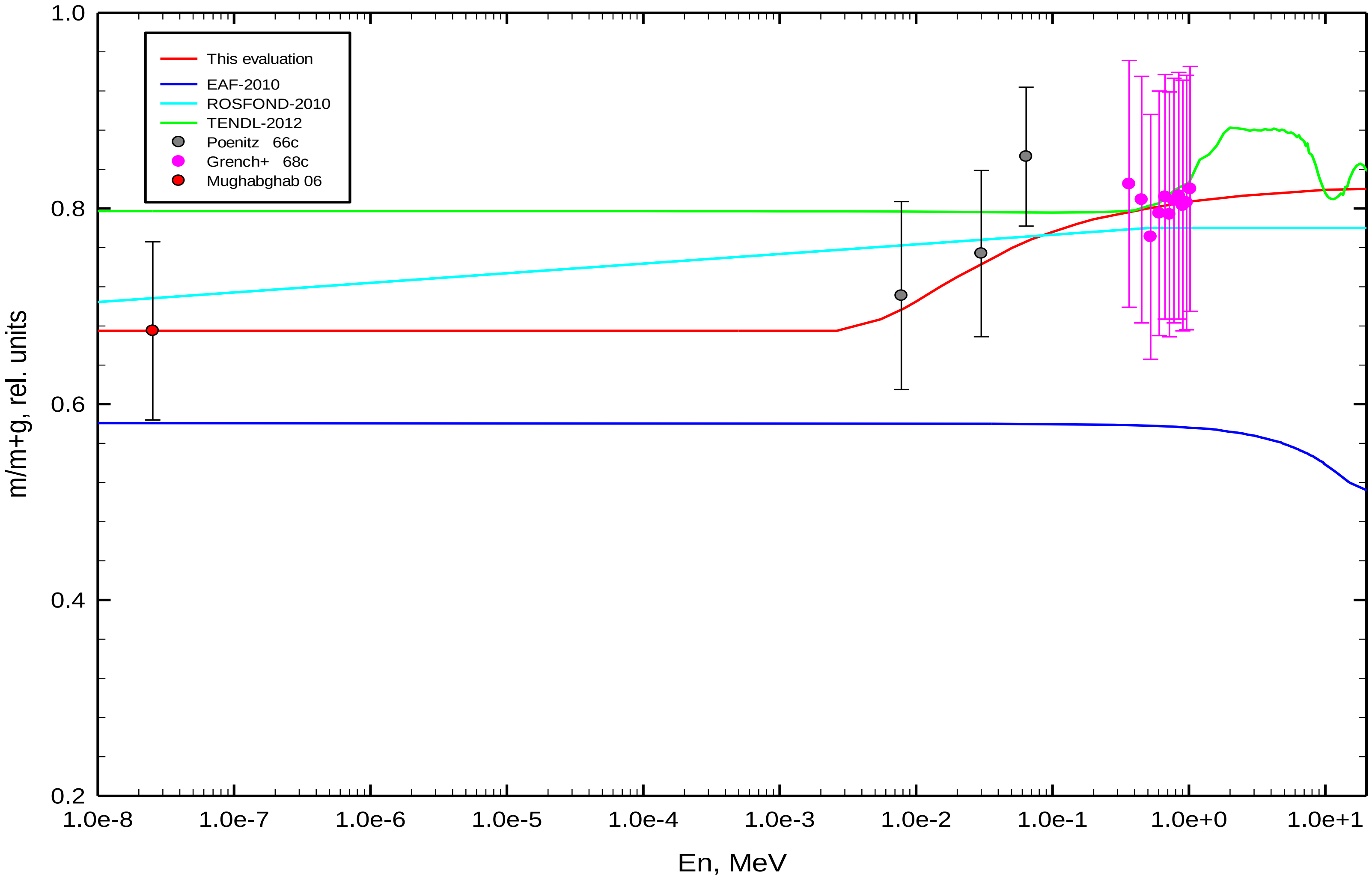

Fig. 4.2. Evaluated cross section ratio of the reactions ^{113}In(n,γ)^{114m}In and ^{113}In(n,γ)$^{114m+g}$In in the energy range (1.0E-8 – 20) MeV in comparison with equivalent data from EAF-2010, ROSFOND-2010, TENDL-2012 and experimental data.

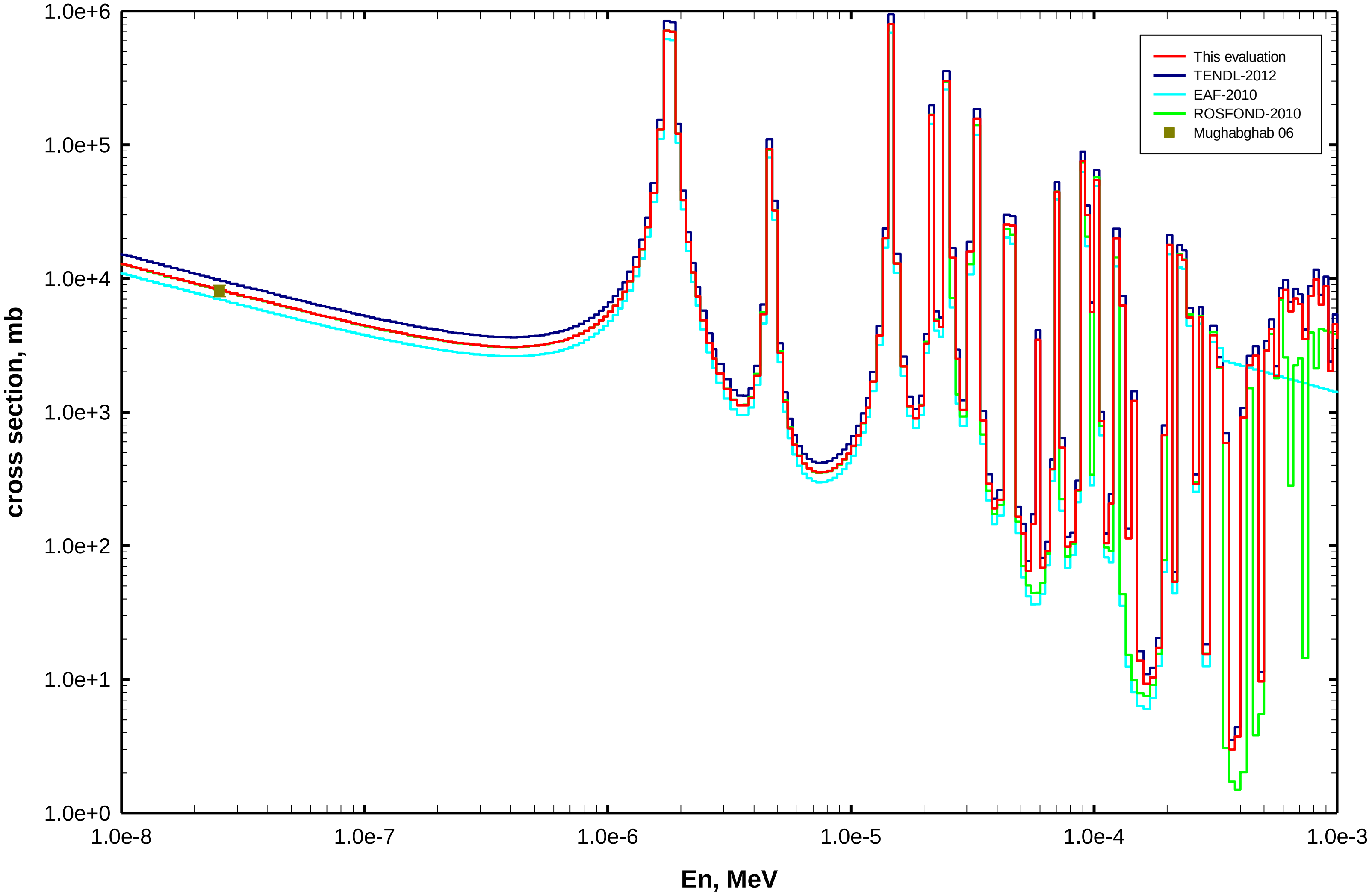

Fig. 4.3. Evaluated ^{113}In(n,γ)^{114m}In reaction excitation function in the energy range (1.0E-8 – 1.0E-3) MeV, in comparison with equivalent data from EAF-2010, ROSFOND-2010, TENDL-2012 and experimental data.

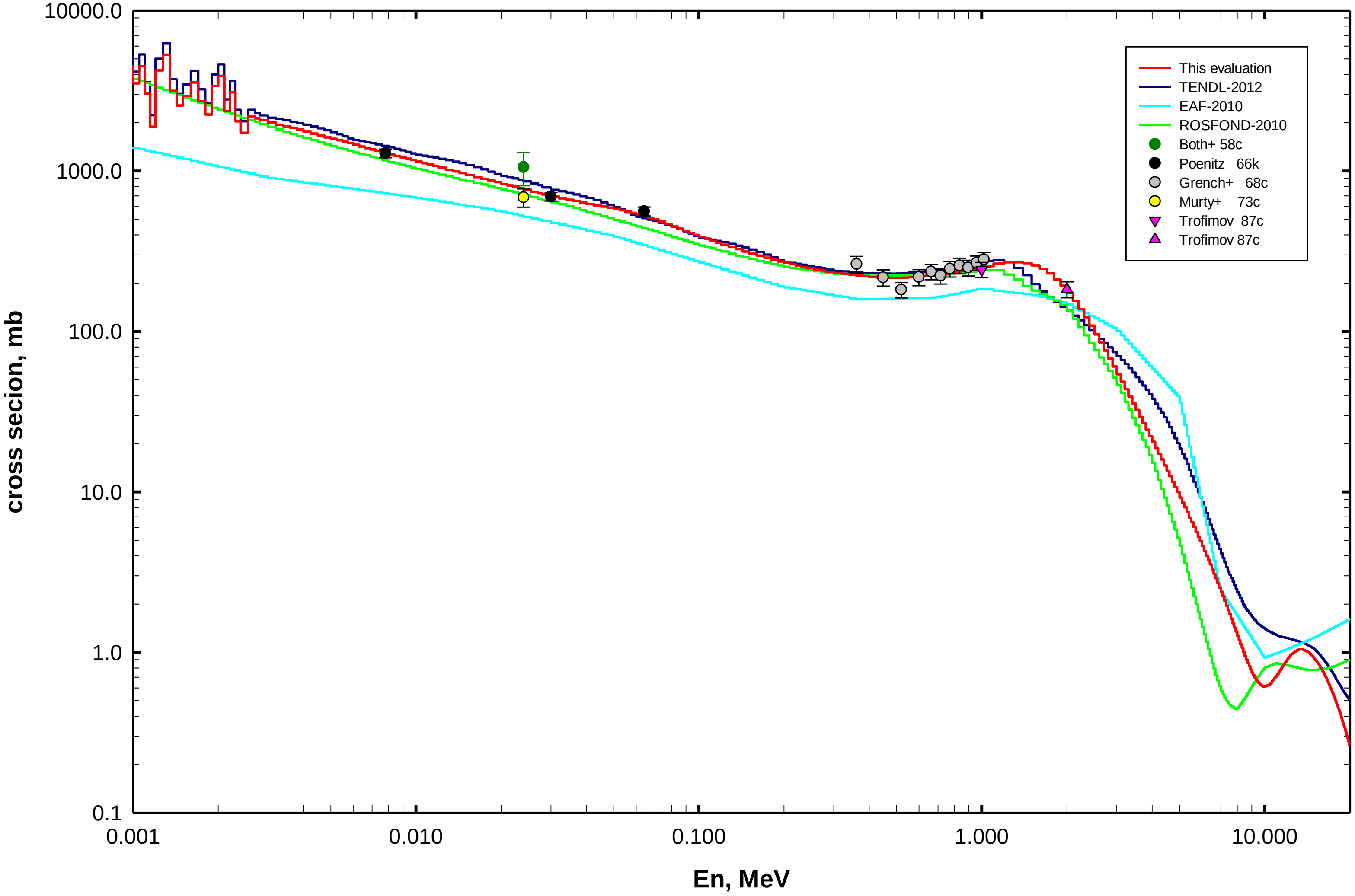

Fig. 4.4. Evaluated ^{113}In(n,γ)^{114m}In reaction excitation function in the energy range (0.001 – 20) MeV, in comparison with equivalent data from EAF-2010, ROSFOND-2010, TENDL-2012 and experimental data.

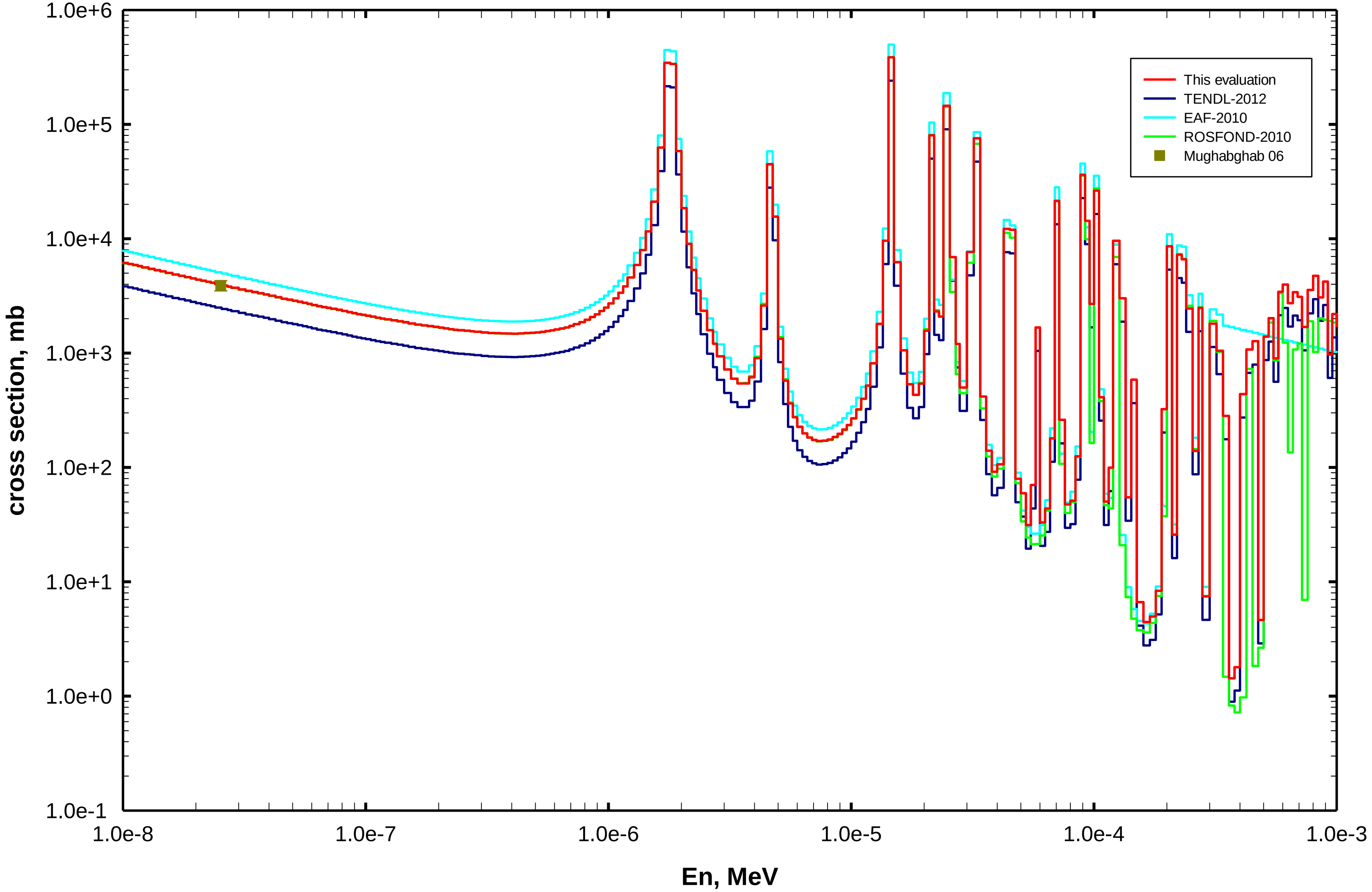

Fig. 4.5. Evaluated ^{113}In(n,γ)^{114g}In reaction excitation function in the energy range (1.0E-8 – 1.0E-3) MeV, in comparison with equivalent data from EAF-2010, ROSFOND-2010, TENDL-2012 and experimental data.

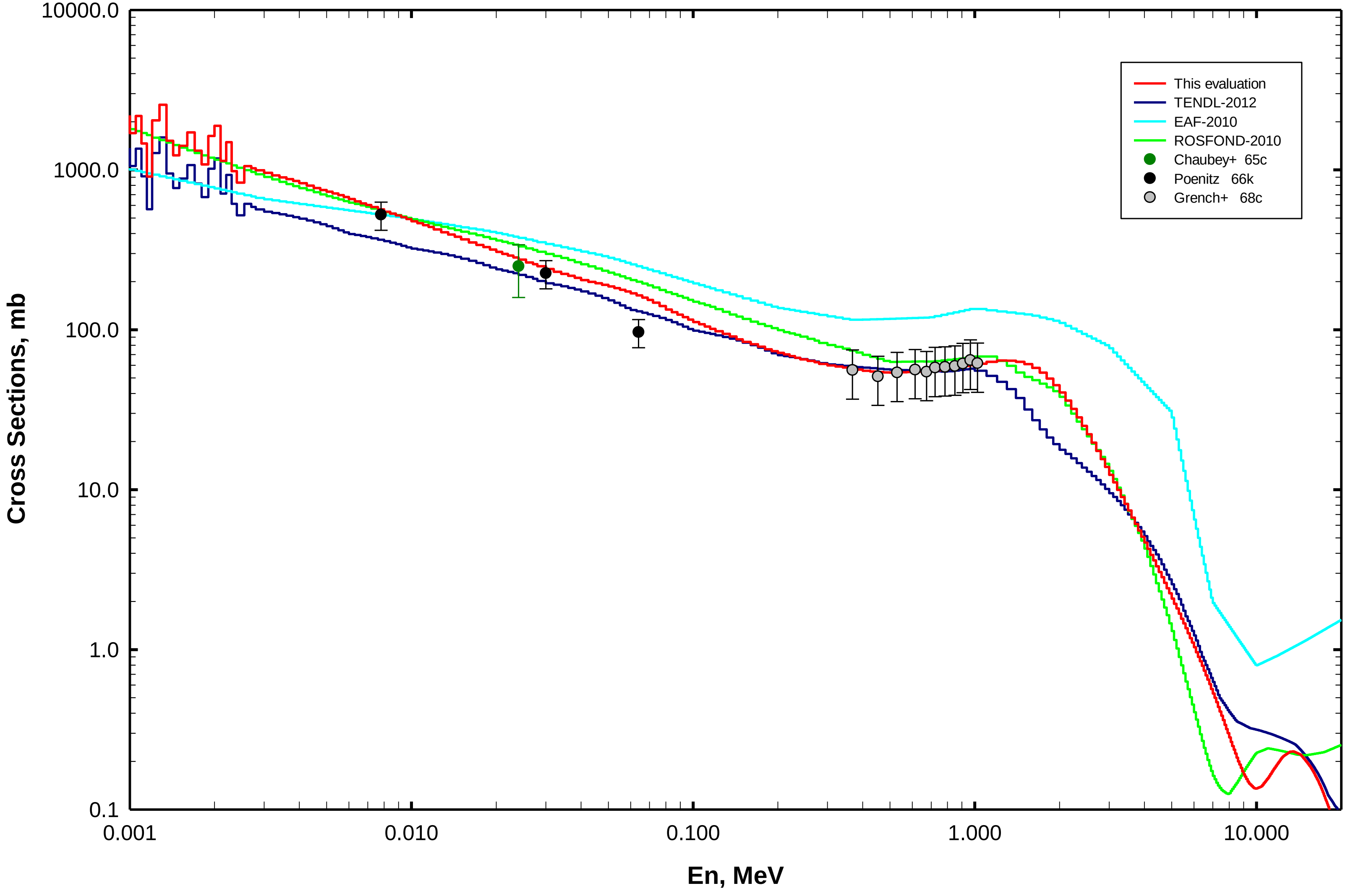

Fig. 4.6. Evaluated ^{113}In(n,γ)^{114g}In reaction excitation function in the energy range (0.001 – 20) MeV, in comparison with equivalent data from EAF-2010, ROSFOND-2010, TENDL-2012 and experimental data.

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CONCLUSION

The new evaluation of cross sections and their uncertainties was carried out for the ^{28}Si(n,p)^{28}Al, ^{31}P(n,p)^{31}Si and ^{113}In(n,γ) reactions.

The ^{28}Si(n,p)^{28}Al and ^{31}P(n,p)^{31}Si reaction excitation functions were evaluated in the energy range from threshold to 21 MeV and from threshold to 60 MeV, respectively. Radiative capture cross section for the minor isotope of indium was evaluated in a wide energy region 1.000E-05 eV – 20 MeV.

In the described new evaluation for the minor indium isotope the ^{113}In(n,tot), ^{113}In(n,el) and ^{113}In(n,γ) reaction excitation functions are determined in the energy range 1.000E-05 eV – 2.619 keV by Reich-Moore resonance parameters, which were obtained for 684 resonances excited by neutrons with orbital moments L = 0 - 2.

Cross sections for the partial reactions ^{113}In(n,γ)^{114g}In and ^{113}In(n,γ)^{114m}In are given as evaluated cross section ratios $\sigma_g(E)/\sigma_{m+g}(E)$ and $\sigma_m(E)/\sigma_{m+g}(E)$. The $R_1(E) = \sigma_g(E)/\sigma_{m+g}(E)$ and $R_2(E) = \sigma_m(E)/\sigma_{m+g}(E)$ values are given at 22 points in the neutron energies range from 1.000E-05 eV to 20 MeV and presented in the MF = 9 sub-file of the new data file for indium-113.

The averaged cross sections $<\sigma>_{U-235}$ and $<\sigma>_{Cf-252}$ calculated with the newly evaluated ^{28}Si(n,p)^{28}Al excitation function agree well with the corresponding experimental data measured in the ^{235}U thermal neutron induced and ^{252}Cf spontaneous fission neutron fields.

The ^{31}P(n,p)^{31}Si integral cross section calculated with the newly evaluated excitation function also agrees well with the cross section measured in the ^{235}U thermal fission neutron spectrum.

The ^{113}In(n,tot), ^{113}In(n,el), ^{113}In(n,γ)^{114g}In and ^{113}In(n,γ)^{114m}In reaction cross sections reconstructed at 0.0253 eV from the new data file for indium-113 agree well with values recommended by S.F. Mughabghab. This is a first evaluation of the ^{113}In(n,γ)^{114m}In reaction excitation function for the reactor dosimetry application.

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