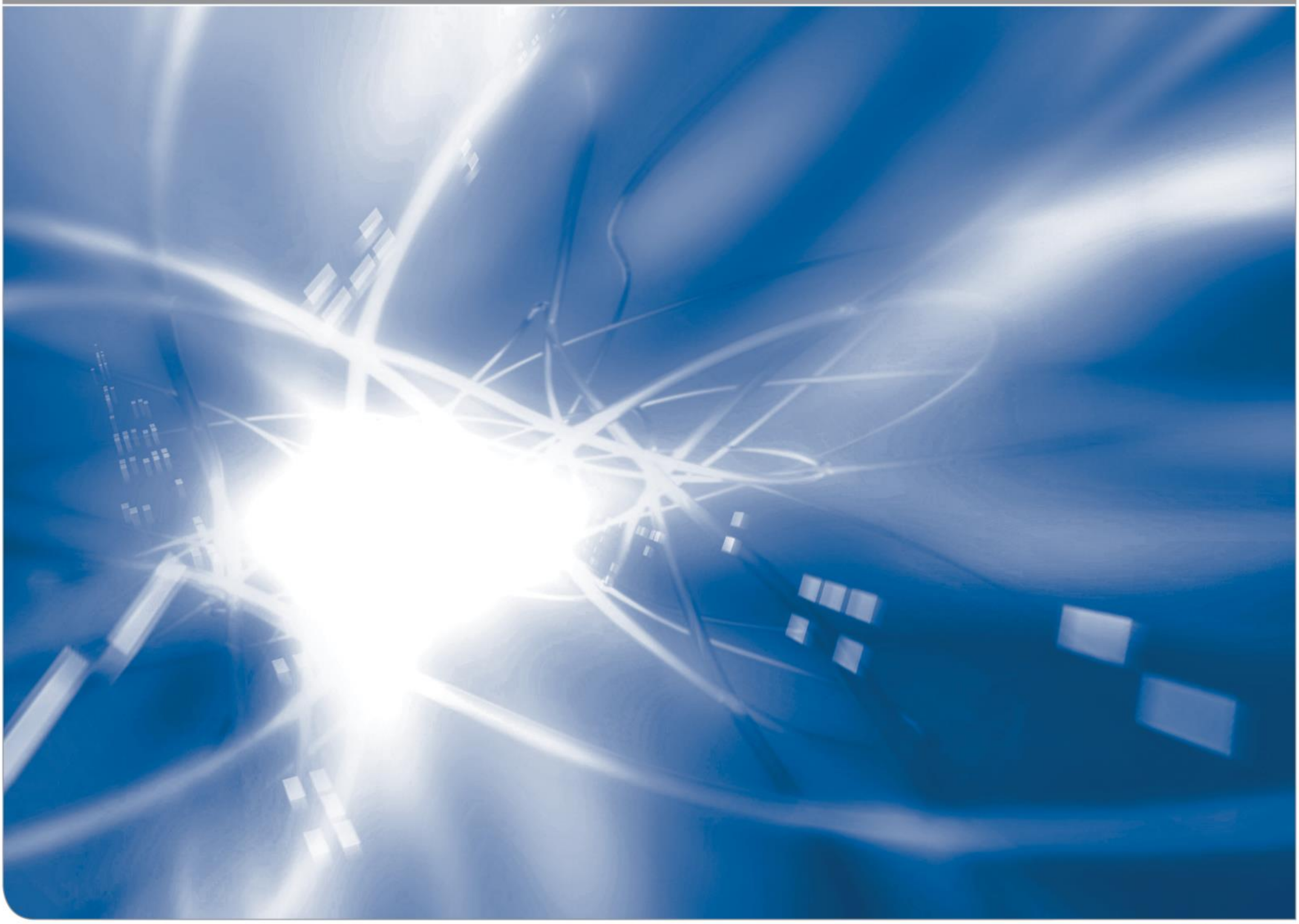
Karlsruhe Institute of Technology

Further improvement of (n,p) and (n,α) reaction cross-sections calculated using the TALYS code

by A.Yu. Konobeyev[1], U. Fischer[1]

KIT SCIENTIFIC WORKING PAPERS 35



[1] Institut für Neutronenphysik und Reaktortechnik,
Karlsruher Institut für Technologie (KIT)

Impressum

Karlsruher Institut für Technologie (KIT)
www.kit.edu

2015

ISSN: 2194-1629

Abstract

A simple approach is proposed for the improvement of calculated cross-sections. The idea is to search for regularities in deviations of measured and calculated reaction cross-section, and the use of obtained information for correction of calculated values.

The approach was applied for improvement of (n,p) and (n,α) reaction cross-sections at 14.5 MeV calculated using the TAYLS code.

CONTENTS

1. Introduction

A discrepancy between experimental and calculated nuclear reaction cross sections is caused mainly by deficiency of nuclear models, uncertainty of model parameters used for calculations, including lack of parameterizations of values used for description of nuclear level density and non-equilibrium particle and cluster emission, and shortcomings of measurements.

The goal of this work is a search for regularities in the deviation of measured and calculated (n,p) and (n,α) reaction cross-sections, and the use of obtained information for an improvement of calculated values. The analysis of deviations is performed for cross-sections calculated using the TALYS code [1] and cross-sections obtained in Refs.[2,3] from the analysis of different experiments for incident 14.5 MeV neutrons for (n,p) and (n,α) reactions.

Details of calculations, the analysis of deviations, and the improvement of calculated data are briefly discussed below.

2. Search for regularities in deviation of experimental and calculated cross-sections

When using modern nuclear models, approximations, and parameterizations as implemented in the TALYS code, the description of the nature of possible systematic deviations of experimental and calculated values in advance is hardly possible.

Consequently, a “blind search” of possible correlations seems a reasonable procedure to analyse deviations of experimental and calculated cross-sections. Some analogy with development of modern systematics of nuclear reaction cross-sections can be found in Refs.[3,4].

In the present work correlations were explored between deviations of calculated and measured cross-sections, and combinations of values such as shell and pairing corrections, separate energies, and elements of systematic formulas [2-4] .

The (n,p) and (n,α) reaction cross-sections at 14.5 MeV were calculated using the TALYS code for target nuclei with atomic number from 18 to 83. The Fermi gas model with the energy dependent level density parameter combined with the “constant temperature” model [1] was applied for calculations of nuclear level density, which selection corresponds to the input TALYS variable *ldmodel* equal to one.

The analysis of the difference between theoretical and measured cross-sections was carried out using data from Refs.[2,3] adopted as an "experimental basis" for construction of systematics for (n,p) and (n,α) reaction cross-sections at 14.5 MeV. Data [2,3] were obtained from the analysis of different measurements, and as a result a single value of (n,p) and (n,α) reaction cross-section was attributed to each target nucleus.

The following deviation factors [5] were used for the quantification of difference between experimental (σ^{exp}), calculated or evaluated (σ) cross-sections

$$H = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{\sigma_i^{exp} - \sigma_i}{\Delta\sigma_i^{exp}}\right)^2 , \qquad (1)$$

$$F = 10^{\left(\frac{1}{N}\sum_{i=1}^{N}\left[\log(\sigma_i^{exp}) - \log(\sigma_i)\right]^2\right)^{1/2}} , \qquad (2)$$

$$R^{EC} = \frac{1}{N}\sum_{i=1}^{N}\frac{\sigma_i^{exp}}{\sigma_i} , \qquad (3)$$

$$R^{CE} = \frac{1}{N}\sum_{i=1}^{N}\frac{\sigma_i}{\sigma_i^{exp}} , \qquad (4)$$

where N is the number of target nuclei,

2.1 (n,p) reaction cross-section

The deviation of experimental and calculated cross-sections was analysed for 125 targets with atomic number from 18 to 83 at primary neutron energy 14.5 MeV.

Figs.1-3 show H, F, and R^{CE} deviation factors calculated for various N values growing with the increase of atomic number of target nucleus. The total value of deviations factor, as usually used for comparison of experimental and theoretical data [5], corresponds to the data on Figs.1-3 for the atomic number 83.

Increasing the value of factors of H, F, and R^{CE} for atomic numbers above 50 indicates systematic deviations of experimental and calculated cross-sections. Further analysis shows, that in particular for targets with Z > 50 calculated (n,p) reaction cross section can be subsequently improved.

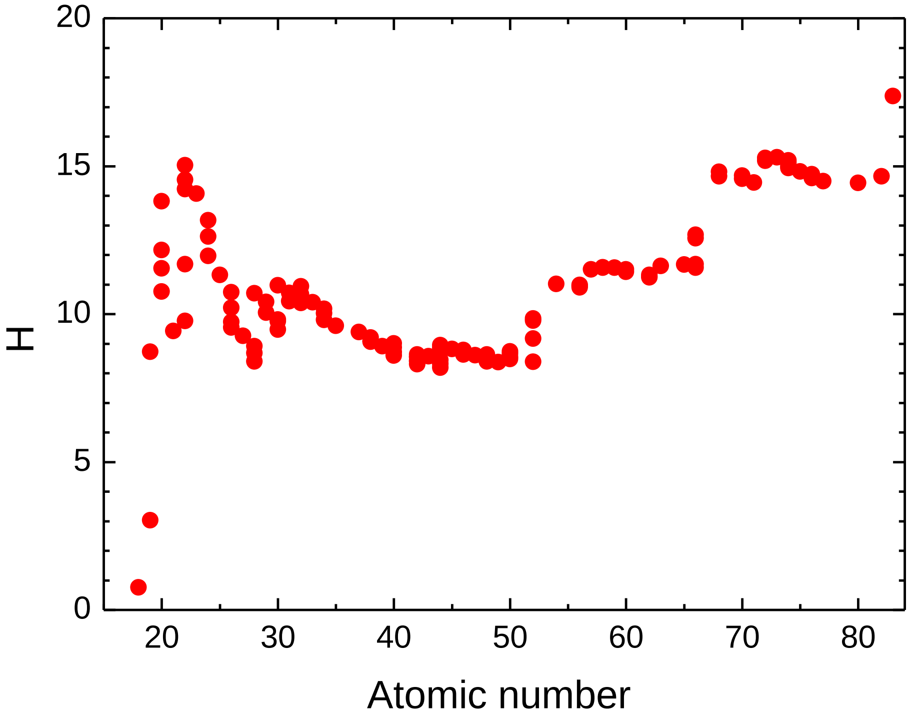


Fig.1 The H-factor, Eq.(1) for (n,p) reaction at 14.5 MeV corresponding to results of TALYS calculations obtained for various N values growing with the increase of atomic number of target nucleus. See details in the text.

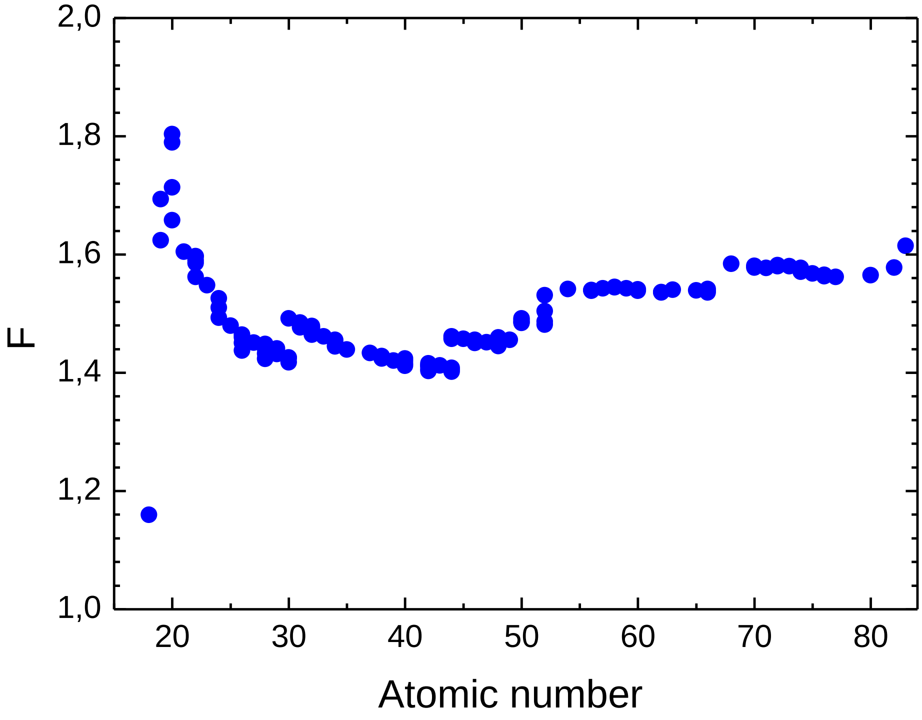


Fig.2 The F-factor, Eq.(2) for (n,p) reaction at 14.5 MeV corresponding to results of TALYS calculations obtained for various N values growing with the increase of atomic number of the target.

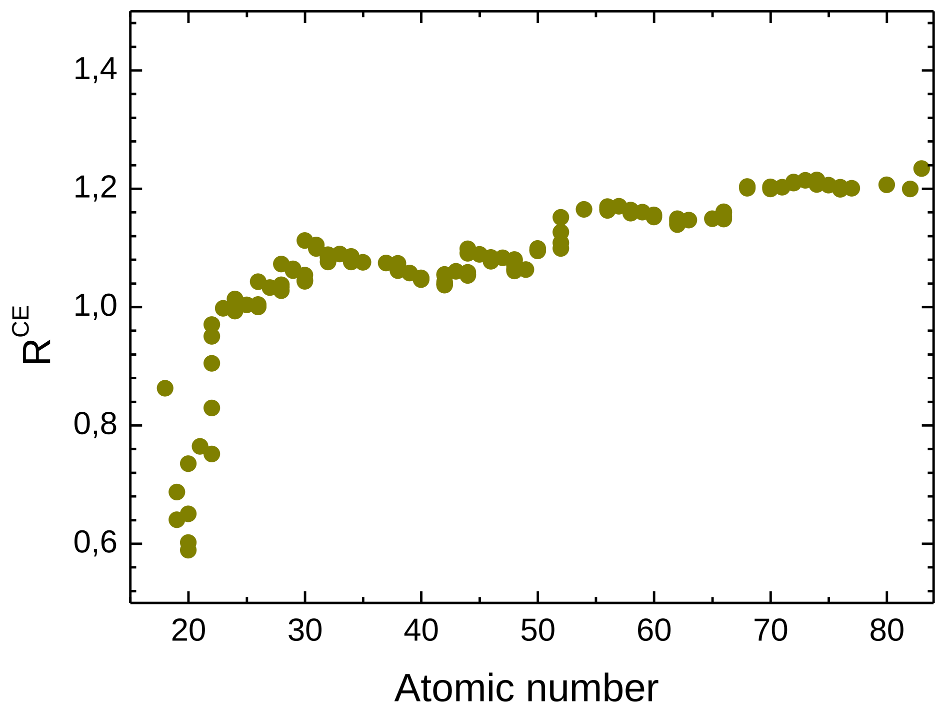


Fig.3 The R^{CE}-factor, Eq.(4) for (n,p) reaction at 14.5 MeV corresponding to results of TALYS calculations obtained for various N values growing with the increase of atomic number of the target.

In contrast to the (n,α) reaction, the deviation of experimental and calculated cross sections has a rather weak correlation (<0.3) with different combinations of shell and pairing corrections, binding energies etc.

The deviation of experimental and calculated cross-sections decreases after a simple correction of calculated values

$$\sigma_{eval} = \sigma_{calc} \exp\left(\left[\alpha_1 \frac{A-2Z}{A} + \alpha_2\right] Q_n\right), \qquad (5)$$

where Z and A are the atomic number and the atomic mass number of the target, Q_n is the separation energy for neutron in the compound nucleus (Z,A+1), the parameter values $\alpha_1 = -0.8209$, and $\alpha_2 = 0.07845$ correspond to target nuclei with $Z \geq 50$.

Table 1 shows the deviation factors, Eq.(1)-(4) corresponding to (n,p) reaction cross-sections calculated using TALYS, σ_{calc} and cross-sections "corrected" using Eq.(5), σ_{eval}. The improvement achieved is moderate. Nevertheless Eq.(5) may be used as an additional information about (n,p) reaction cross sections at 14.5 MeV.

Table 2 presents (n,p) reaction cross-sections for target nuclei with the atomic number between 50 and 84 with the half-life $T_{1/2}$ more than one hour calculated using the TALYS code and Eq.(5).

Table 1. Deviation factors for (n,p) reaction cross-sections at 14.5 MeV for 46 nuclei with atomic number from 50 to 83.

Factor	Cross-sections calculated using TALYS	Cross-sections evaluated using Eq.(5)
H	32.8	14.2
F	1.85	1.80
R^{EC}	0.91	1.39
R^{CE}	1.53	0.98

2.2 (n,α) reaction cross-section

The analysis of deviations of theoretical and experimental cross-sections was performed for 120 targets with atomic number from 18 to 83.

As opposed to the (n,p) reaction, the deviations for (n,α) reaction show definite correlations (up to 0.75) with definite combinations of values relating to neutron interactions with investigated nuclei. The proposed formula for the subsequent improvement of calculated cross-sections is as follows

$$\sigma_{eval} = \sigma_{calc} \exp\left(\left[\beta_1 \frac{A-2Z}{A} + \beta_2\right]\left[Q_n - Q_p + (dW_{Z,A} - dW_{Z-1,A-3}) - (\delta_{Z,A} - \delta_{Z-1,A-3})\right]\right), \quad (6)$$

where Z and A are the atomic number and the atomic mass number of the target, Q_n and Q_n are separation energies for neutron and proton in (Z,A+1) nucleus, parameter values β_1 = –1.523 and β_2 = 0.07503 correspond to target nuclei with the atomic number from 18 to 83.

Table 3 shows the deviation factors for cross-sections calculated using TALYS and cross-sections improved using Eq.(6). Fig.4 shows the ratio of calculated and corrected cross-sections to experimental ones. In contrast to (n,p) reaction the improvement achieved is essential.

Table 2. (n,p) reaction cross-sections at 14.5 MeV for target nuclei ("Z A") with the atomic number between 50 and 84 with the half-life more than one hour evaluated using Eq.(5) ("Improved"), calculated using the TALYS code ("TALYS"), and obtained from the analysis of experimental data ("Expr data").

Z	A	Improved	TALYS	Expr data
50	110	185.7	180.0	
50	112	73.62	79.24	21.8 ± 9.4
50	113	43.85	51.70	
50	114	17.76	21.03	
50	115	24.22	31.85	
50	116	8.577	10.92	
50	117	11.43	16.72	14.5 ± 1.5
50	118	4.357	5.900	5.93 ± 0.59
50	119	6.191	9.996	6.98 ± 2.16
50	120	1.947	2.792	
50	121	3.455	6.075	
50	122	0.745	1.127	
50	123	1.793	3.390	
50	124	0.259	0.410	
50	125	0.878	1.772	
50	126	0.0776	0.128	
50	127	0.323	0.694	
51	117	32.30	39.41	
51	119	19.86	26.07	
51	121	12.43	17.52	
51	122	19.79	32.73	
51	123	8.415	12.54	
51	124	13.99	25.11	
51	125	5.383	8.449	
51	126	10.16	19.52	
51	127	3.413	5.622	
51	128	7.200	14.68	
51	129	2.184	3.728	
52	116	145.5	153.1	
52	117	85.81	98.33	
52	118	54.87	63.31	
52	119	42.68	55.18	
52	120	21.87	27.38	
52	121	25.48	36.63	
52	122	11.40	15.32	14.2 ± 1.4
52	123	15.29	24.13	
52	124	6.825	9.729	
52	125	10.16	17.46	
52	126	4.338	6.523	3.48 ± 0.35
52	127	6.365	11.79	
52	128	2.837	4.490	1.67 ± 0.36
52	129	4.394	8.663	
52	130	1.607	2.671	0.805± 0.467
52	132	1.086	1.895	
53	120	65.27	78.38	
53	121	39.72	47.76	
53	123	23.56	30.63	
53	124	28.60	42.18	
53	125	15.49	21.57	
53	126	21.13	33.94	
53	127	9.677	14.31	
53	129	7.141	11.10	
53	130	12.30	23.03	
53	131	4.959	8.137	
53	132	8.371	16.64	
53	133	3.191	5.534	
53	135	0.671	0.976	
54	122	71.12	80.62	
54	123	53.42	67.03	
54	124	29.52	36.37	
54	125	27.92	38.94	
54	126	15.57	20.63	
54	127	17.43	26.69	
54	128	8.974	12.66	
54	129	11.58	19.29	
54	130	5.773	8.607	
54	131	7.677	13.89	5.94 ± 0.75
54	132	3.687	5.776	
54	133	5.431	10.39	
54	134	2.690	4.500	
54	135	3.559	7.118	
54	136	0.302	0.435	
55	127	25.76	32.88	
55	129	17.49	24.03	
55	131	13.41	19.63	
55	132	18.68	31.57	
55	133	9.654	14.96	
55	134	14.11	25.74	
55	135	6.909	11.42	
55	136	10.35	19.82	
55	137	2.068	2.987	
56	126	140.8	156.4	
56	128	41.39	49.92	
56	129	35.56	48.26	
56	130	20.80	27.08	
56	131	21.08	31.42	
56	132	11.69	16.26	
56	133	13.42	21.78	
56	134	7.796	11.55	
56	135	9.893	17.31	
56	136	5.813	9.196	7.22 ± 0.72
56	137	6.602	12.20	8.28 ± 1.95
56	138	1.186	1.699	2.80 ± 0.28
56	139	1.924	3.239	
56	140	0.533	0.786	
57	132	38.27	53.21	
57	133	21.59	29.22	
57	135	16.20	23.39	
57	137	12.45	19.37	
57	138	16.09	28.30	
57	139	4.854	6.937	3.87 ± 0.39
57	140	8.768	14.38	
57	141	2.858	4.291	
57	142	5.799	9.742	
58	132	53.35	63.16	
58	133	43.92	57.98	
58	134	28.51	36.61	
58	135	25.65	37.11	
58	136	16.51	22.65	
58	137	17.63	27.94	
58	138	11.45	16.93	
58	139	11.46	19.43	
58	140	3.027	4.244	7.21 ± 0.72
58	141	4.305	6.964	
58	142	1.924	2.785	4.44 ± 0.46
58	143	2.458	4.168	
58	144	0.809	1.185	
59	137	33.68	44.71	
59	139	21.17	30.41	
59	141	9.196	12.71	9.64 ± 0.96
59	142	14.32	22.31	
59	143	26.50	38.53	
59	145	3.641	5.331	
60	138	38.73	48.79	
60	140	23.26	31.74	
60	141	20.76	31.93	
60	142	7.127	9.606	12.8 ± 1.3
60	143	8.395	12.76	
60	144	4.702	6.580	
60	145	5.235	8.437	
60	146	1.980	2.834	3.56 ± 0.36

Table 2 continued

60 147	3.117	5.297	
60 148	1.165	1.716	
60 149	2.116	3.855	
60 150	0.677	1.069	
61 143	16.44	21.64	
61 144	22.32	32.38	
61 145	11.10	15.34	
61 146	16.70	25.75	
61 147	7.033	10.09	
61 148	12.57	20.27	
61 149	5.107	7.573	
61 150	9.221	16.60	
61 151	3.176	5.084	
62 142	62.73	78.19	
62 144	16.13	20.52	23.4 ± 4.6
62 145	18.04	25.36	
62 146	9.142	12.18	
62 147	10.18	15.29	
62 148	5.502	7.584	11.6 ± 2.2
62 149	6.408	10.29	
62 150	2.788	3.985	6.39 ± 0.64
62 151	5.211	9.162	
62 152	2.637	4.042	
62 153	3.996	7.389	
62 154	1.881	3.018	
62 156	0.748	1.215	
63 145	26.49	32.67	
63 146	33.04	44.11	
63 147	19.13	24.93	
63 148	25.73	36.80	
63 149	12.38	16.89	
63 150	18.67	28.40	
63 151	8.670	12.46	
63 152	13.93	23.66	
63 153	6.204	9.517	4.96 ± 0.66
63 154	10.31	18.37	
63 155	4.225	6.803	
63 156	6.726	12.15	
63 157	2.390	3.905	
64 146	39.78	47.01	
64 147	29.30	37.57	
64 148	20.33	25.46	
64 149	18.99	26.27	
64 150	10.88	14.29	
64 151	11.77	17.56	
64 152	6.324	8.706	
64 153	9.629	15.80	
64 154	5.475	8.062	
64 155	7.345	12.74	
64 156	4.179	6.476	
64 157	4.787	8.557	
64 158	2.348	3.720	
64 159	2.722	4.999	
64 160	1.105	1.791	
65 147	64.29	73.18	
65 148	50.17	60.85	
65 149	34.59	42.32	
65 150	40.90	53.38	
65 151	22.18	28.65	
65 152	30.10	42.71	
65 153	15.05	20.54	
65 154	21.17	33.32	
65 155	11.18	16.23	
65 156	15.41	25.68	
65 157	8.163	12.49	
65 158	11.05	19.06	
65 159	5.111	8.052	5.72 ± 0.57
65 160	7.735	13.83	
65 161	3.184	5.252	
66 152	25.50	31.45	
66 153	23.48	32.30	
66 154	13.35	17.41	
66 155	18.83	28.36	
66 156	11.37	15.87	
66 157	14.33	23.00	
66 158	8.530	12.56	
66 159	9.733	16.42	
66 160	5.307	8.084	7.61 ± 0.97
66 161	6.088	10.75	
66 162	3.768	5.978	3.99 ± 0.40
66 163	3.540	6.417	3.08 ± 0.31
66 164	1.492	2.380	2.48 ± 0.27
66 165	1.853	3.390	
66 166	0.837	1.361	
67 161	10.33	15.56	
67 163	7.334	11.52	
67 165	3.996	6.414	
67 166	5.900	10.55	
67 167	2.460	4.016	
68 158	21.85	28.42	
68 160	14.59	20.13	
68 161	16.68	26.20	
68 162	10.90	15.74	
68 163	12.33	20.52	
68 164	7.617	11.48	
68 165	8.615	15.05	
68 166	4.540	7.119	
68 167	4.740	8.420	1.50 ± 0.45
68 168	2.523	4.027	2.58 ± 0.26
68 169	2.795	5.063	
68 170	1.315	2.140	
68 171	1.493	2.754	
68 172	0.520	0.848	
69 163	18.42	25.99	
69 165	12.62	18.70	
69 166	15.58	26.31	
69 167	8.781	13.61	
69 168	11.61	20.07	
69 169	5.333	8.580	
69 170	7.137	12.61	
69 171	3.294	5.423	
69 172	5.078	9.093	
69 173	1.849	3.042	
70 164	17.89	24.31	
70 166	12.51	17.83	
70 168	9.629	14.38	
70 169	10.03	17.00	
70 170	6.597	10.24	
70 171	6.323	11.12	
70 172	4.051	6.500	
70 173	3.737	6.696	
70 174	1.978	3.187	2.86 ± 0.29
70 175	2.189	3.944	
70 176	0.892	1.468	1.76 ± 0.19
70 177	1.011	1.901	
70 178	0.251	0.404	
71 169	15.91	23.37	
71 170	18.23	29.69	
71 171	10.78	16.48	
71 172	13.04	22.19	
71 173	7.711	12.27	
71 174	9.196	16.04	
71 175	4.705	7.605	5.08 ± 4.05
71 176	6.310	11.12	
71 177	3.064	5.079	
71 179	1.648	2.769	
72 170	16.71	23.52	
72 171	16.80	26.68	
72 172	11.63	17.18	
72 173	12.05	19.93	
72 174	8.427	12.87	
72 175	8.497	14.68	
72 176	5.212	8.186	
72 177	4.973	8.783	
72 178	3.180	5.128	2.54 ± 0.25
72 179	3.046	5.586	
72 180	1.696	2.764	1.94 ± 0.38

Table 2 continued

72 181	1.678	3.059	
72 182	0.767	1.256	
72 183	0.914	1.677	
72 184	0.323	0.527	
73 173	19.08	27.58	
73 174	21.32	34.08	
73 175	12.94	19.40	
73 176	14.73	24.73	
73 177	8.579	13.51	
73 179	5.542	8.997	
73 180	7.525	13.45	
73 181	3.330	5.419	3.55 ± 0.35
73 182	4.733	8.470	
73 183	2.091	3.418	
73 184	3.437	6.285	
74 176	12.44	18.05	
74 177	12.82	20.97	
74 178	9.088	13.79	
74 180	5.954	9.350	
74 181	6.138	10.90	
74 182	3.293	5.236	4.36 ± 0.44
74 183	3.356	6.006	4.81 ± 0.48
74 184	1.567	2.514	2.96 ± 0.30
74 185	2.004	3.712	
74 186	0.750	1.222	1.64 ± 0.16
74 187	1.057	1.992	
74 188	0.264	0.429	
75 181	10.44	16.13	
75 182	13.08	22.80	
75 183	6.514	10.23	
75 184	8.256	14.48	
75 185	4.013	6.453	
75 186	6.184	11.18	
75 187	2.580	4.224	4.08 ± 0.45
75 188	4.313	7.980	
75 189	1.358	2.286	
76 181	17.18	27.89	
76 182	11.73	17.60	
76 183	12.40	20.96	
76 184	7.625	11.68	
76 185	7.840	13.75	
76 186	4.472	7.016	
76 187	4.670	8.517	
76 188	2.453	3.910	4.95 ± 0.56
76 189	2.833	5.378	6.83 ± 2.39
76 190	1.269	2.079	
76 191	1.541	3.023	
76 192	0.436	0.732	
76 193	0.704	1.394	
76 194	0.185	0.308	
77 184	20.51	33.39	
77 185	13.58	20.43	
77 186	17.02	28.93	
77 187	8.930	14.10	
77 188	11.19	19.83	
77 189	5.817	9.296	
77 190	8.337	15.48	
77 191	3.912	6.446	
77 192	6.032	11.59	
77 193	2.315	3.935	2.89 ± 0.77
77 194	4.299	8.291	
77 195	1.245	2.153	
78 185	22.43	35.69	
78 186	14.48	21.00	
78 187	14.28	24.29	
78 188	9.569	14.45	
78 189	9.895	17.64	
78 190	5.208	8.098	
78 191	6.180	11.53	
78 192	3.045	4.885	
78 193	3.896	7.533	
78 194	1.944	3.214	
78 195	2.176	4.291	
78 196	0.934	1.572	
78 197	1.173	2.358	
78 198	0.453	0.770	
78 200	0.174	0.296	
78 202	0.0563	0.0970	
79 175	223.2	225.8	
79 191	9.117	14.24	
79 192	13.88	24.85	
79 193	6.421	10.42	
79 194	10.05	18.72	
79 195	4.231	7.070	
79 196	6.926	13.29	
79 197	2.440	4.218	
79 198	4.505	8.740	
79 199	1.487	2.613	
80 192	10.26	15.55	
80 193	11.15	19.69	
80 194	6.596	10.35	
80 195	7.571	13.98	
80 196	4.164	6.803	
80 197	4.669	8.877	
80 198	2.660	4.506	
80 199	2.853	5.531	2.87 ± 1.09
80 200	1.561	2.663	
80 201	1.806	3.602	
80 202	0.898	1.561	
80 203	1.050	2.147	
80 204	0.366	0.641	
81 195	13.04	20.41	
81 196	16.89	29.86	
81 197	9.373	15.25	
81 198	12.19	22.48	
81 199	7.064	11.93	
81 200	8.953	16.91	
81 201	4.202	7.328	
81 202	6.157	11.91	
81 203	2.546	4.554	
81 204	4.107	8.135	
81 205	1.350	2.484	
82 198	12.41	19.53	
82 199	12.03	21.91	
82 200	8.627	14.09	
82 201	8.063	15.23	
82 202	5.423	9.173	
82 203	5.275	10.26	
82 204	3.407	5.937	
82 205	3.292	6.585	
82 206	1.975	3.596	
82 207	1.569	3.092	
82 208	0.215	0.313	0.883± 0.088
82 209	0.343	0.572	
82 210	0.0943	0.139	
82 212	0.0430	0.0641	
83 201	17.68	28.48	
83 202	20.41	37.23	
83 203	13.78	22.99	
83 204	15.90	29.91	
83 205	10.43	18.02	
83 206	12.69	24.44	
83 207	8.845	15.79	
83 208	9.914	19.02	
83 209	2.836	4.300	0.780± 0.187
83 210	4.637	7.499	
83 212	3.569	5.983	
84 204	15.17	24.54	
84 205	14.28	26.28	
84 206	10.73	17.93	
84 207	10.63	20.16	
84 208	8.384	14.58	
84 209	7.580	14.27	
84 210	3.245	4.794	

Table 3. Deviation factors for (n,α) reaction cross-sections at 14.5 MeV for 120 nuclei with atomic number from 18 to 83.

Factor	Cross-sections calculated using TALYS	Cross-sections evaluated using Eq.(6)
H	25.6	12.5
F	2.89	1.66
R^{EC}	3.03	1.33
R^{CE}	0.75	0.95

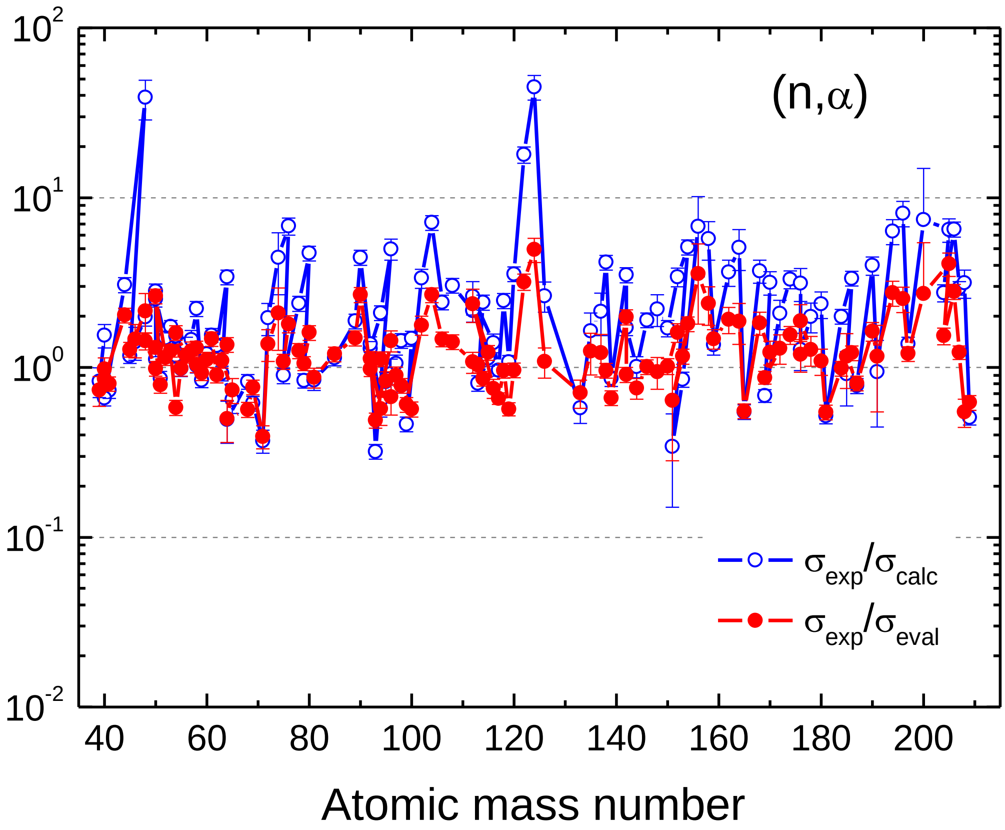


Fig.4 The ratio of experimental (n,α) reaction cross-sections for 120 target nuclei irradiated with 4.5 MeV neutrons to cross-sections calculated with TALYS and cross-sections evaluated using Eq.(6).

Observed improvement is a result of the use of the set of values in Eq.(6), which full explanation seems rather complicated. With some fantasy one can detect quantities relating to “coalescence” of α-particle from proton and “pre-formed” triton. One thing is clear – the formula Eq.(6) compensates in some way the shortcomings of the theory describing the non-equilibrium emission of α-particles, global parameterizations and nuclear model parameter systematics used for calculations.

Table 4 shows (n,α) reaction cross-sections for target nuclei with the atomic number between 18 and 84 with the half-life $T_{1/2}$ more than one hour calculated using the TALYS code, values improved using Eq.(6), and data obtained in Ref.[3] from the analysis of experimental data.

3. Conclusion

The simple approach is proposed for the improvement of calculated cross-sections. The idea concerns the search of correlations between deviations of measured and calculated reaction cross-section, and nuclear quantities relating to reactions investigated. The obtained information is used subsequently for correction of calculated values.

The approach was applied for improvement of (n,p) and (n,α) reaction cross-sections at 14.5 MeV calculated using the TAYLS code. The new evaluated cross-sections are given in Table 2 and Table 4.

Table 4. (n,α) reaction cross-sections at 14.5 MeV for target nuclei ("Z A") with the atomic number between 18 and 84 with the half-life more than one hour evaluated using Eq.(6) ("Improved"), calculated using the TALYS code ("TALYS"), and obtained from the analysis of experimental data ("Expr data").

Z	A	Improved	TALYS	Expr data
18	36	175.6	203.5	
18	37	121.6	116.0	
18	38	60.39	59.07	
18	39	46.11	43.14	
18	40	11.01	6.995	10.8 ± 1.7
18	41	10.38	6.242	
18	42	2.820	0.663	
19	39	176.4	157.0	130. ± 26.
19	40	150.5	151.4	
19	41	41.54	45.61	33.3 ± 3.3
19	42	40.16	49.44	
19	43	12.41	10.89	
20	40	149.6	193.8	128. ± 13.
20	41	144.2	137.8	
20	42	59.18	59.47	
20	43	45.67	44.21	
20	44	13.64	9.033	27.7 ± 2.8
20	45	8.990	5.399	
20	46	2.800	0.797	
20	47	1.345	0.319	
20	48	0.580	0.0321	1.25 ± 0.33
21	43	220.7	159.2	
21	44	108.0	103.3	
21	45	44.26	48.20	56.4 ± 5.6
21	46	29.15	35.54	
21	47	11.87	11.93	
21	48	3.360	3.555	
22	44	119.5	127.3	
22	45	122.8	112.1	
22	46	52.29	54.15	76.5 ± 16.9
22	47	66.21	63.33	
22	48	23.73	17.16	34.0 ± 3.9
22	49	10.49	7.517	
22	50	8.762	3.061	8.63 ± 0.86
23	48	86.54	81.51	
23	49	43.97	46.26	
23	50	29.10	34.09	38.0 ± 1.5
23	51	20.96	19.16	16.5 ± 1.7
24	48	78.32	88.35	
24	50	37.89	39.52	99.7 ± 10.0
24	51	44.96	44.63	
24	52	31.66	24.34	36.2 ± 3.6
24	53	35.29	25.39	44.2 ± 3.7
24	54	20.30	10.02	11.8 ± 1.2
25	52	106.5	96.64	
25	53	65.00	66.58	
25	54	41.05	45.51	
25	55	24.27	24.40	24.0 ± 2.4
25	56	12.80	14.35	
26	51	229.5	129.8	
26	52	89.24	94.63	
26	54	56.95	59.61	91.1 ± 9.1
26	55	64.02	63.58	
26	56	37.27	32.09	43.9 ± 4.4
26	57	24.75	21.24	31.0 ± 4.0
26	58	15.25	8.932	19.8 ± 2.0
26	59	5.680	3.352	
26	60	2.139	0.692	
27	55	155.4	123.6	
27	56	151.8	134.3	
27	57	108.4	110.5	
27	58	62.73	73.68	
27	59	33.89	37.31	31.4 ± 3.1
27	60	15.35	19.11	
27	61	8.732	8.260	
28	56	87.93	100.1	
28	57	119.8	109.1	
28	58	104.9	105.9	109. ± 11.
28	59	93.37	93.72	
28	60	56.36	52.32	62.8 ± 6.3
28	61	30.17	28.69	44.4 ± 4.2
28	62	25.99	17.38	23.4 ± 2.3
28	63	9.254	6.578	
28	64	2.766	1.106	3.77 ± 0.38
28	65	2.217	0.929	
28	66	0.297	0.0553	
29	61	124.8	124.6	
29	63	40.46	48.05	44.4 ± 4.4
29	64	26.89	37.70	
29	65	11.80	13.47	8.69 ± 1.48
29	67	3.365	3.232	
30	62	150.7	139.9	
30	64	72.87	73.58	36.4 ± 10.1
30	65	54.11	61.06	
30	66	28.27	25.36	
30	67	25.01	26.88	
30	68	15.96	10.93	9.02 ± 0.90
30	70	6.706	2.896	
30	72	1.114	0.251	
31	66	98.15	114.5	
31	67	70.95	86.02	
31	68	51.91	75.05	
31	69	26.37	32.85	20.2 ± 2.0
31	71	12.91	13.71	5.06 ± 0.78
31	72	10.49	14.86	
31	73	3.649	2.968	
32	66	115.5	105.9	
32	68	79.11	80.03	
32	69	75.66	85.42	
32	70	31.76	29.81	
32	71	28.46	31.25	
32	72	12.65	8.883	17.4 ± 3.7
32	73	13.21	12.08	
32	74	3.762	1.776	7.89 ± 3.14
32	75	5.803	3.201	
32	76	1.398	0.371	2.52 ± 0.29
32	77	1.703	0.551	
32	78	0.204	0.0307	
33	71	85.46	103.3	
33	72	65.18	96.80	
33	73	34.36	45.64	
33	74	25.17	40.53	
33	75	9.860	11.95	10.7 ± 1.1
33	76	10.01	14.67	
33	77	4.511	4.300	
33	78	3.402	3.804	
34	72	76.26	76.64	
34	73	96.96	106.9	
34	74	40.99	38.04	
34	75	39.69	41.60	
34	76	13.89	10.04	
34	77	18.07	15.85	
34	78	6.230	3.282	7.81 ± 0.78
34	79	9.170	5.832	
34	80	2.052	0.699	3.29 ± 0.33
34	82	0.585	0.101	
35	75	77.52	92.12	

Table 4 continued

35	76	53.91	74.71	
35	77	33.08	43.49	
35	79	11.82	14.94	12.5 ± 1.2
35	81	5.136	5.319	4.48 ± 0.59
35	82	3.938	4.616	
35	83	1.944	1.273	
36	76	65.51	65.75	
36	77	84.87	90.29	
36	78	39.82	36.99	
36	79	44.95	48.22	
36	80	14.93	11.59	
36	81	17.27	15.90	
36	82	5.356	3.147	
36	83	7.759	5.630	
36	84	4.282	1.615	
36	85	2.586	1.211	
36	86	0.434	0.0762	
36	87	2.227	0.492	
36	88	0.679	0.120	
37	81	33.09	43.52	
37	83	12.84	16.84	
37	84	10.72	15.78	
37	85	4.982	5.255	5.97 ± 0.60
37	86	5.199	5.432	
37	87	1.443	0.811	
38	80	71.50	71.59	
38	82	35.42	34.06	
38	83	44.88	48.02	
38	84	16.10	13.26	
38	85	18.28	17.05	
38	86	4.736	2.995	
38	87	6.233	4.421	
38	88	3.333	1.034	
38	89	6.968	2.903	
38	90	2.477	0.919	
38	91	1.888	0.738	
38	92	1.097	0.249	
39	85	33.57	43.66	
39	86	24.73	37.45	
39	87	12.20	15.22	
39	88	8.144	11.29	
39	89	4.210	3.346	6.27 ± 0.63
39	90	14.56	15.04	
39	91	4.949	5.758	
39	92	2.824	3.529	
39	93	2.629	2.360	
40	86	36.90	36.22	
40	87	43.12	46.82	
40	88	14.53	12.88	
40	89	16.17	16.38	
40	90	5.104	3.076	13.7 ± 1.4
40	91	19.88	14.74	
40	92	9.522	7.229	9.32 ± 0.93
40	93	6.941	5.580	
40	94	4.125	2.213	4.63 ± 0.46
40	95	2.799	1.504	
40	96	1.615	0.465	2.32 ± 0.33
40	97	1.358	0.411	
41	89	34.60	43.81	
41	90	29.99	43.51	
41	91	19.77	21.87	
41	92	38.57	51.74	
41	93	18.12	27.69	8.85 ± 0.89
41	94	11.82	20.84	
41	95	9.616	13.71	
41	96	5.358	8.640	
41	97	4.892	5.477	
42	90	34.63	34.56	
42	92	22.77	18.71	25.7 ± 2.6
42	93	55.17	51.65	
42	94	22.78	20.42	13.0 ± 2.6
42	95	15.48	15.68	12.9 ± 1.7
42	96	11.86	8.695	7.98 ± 1.77
42	97	9.356	7.957	8.41 ± 0.99
42	98	7.705	4.195	6.02 ± 0.60
42	99	8.300	5.583	
42	100	5.044	1.931	2.86 ± 0.29
43	93	44.95	51.29	
43	94	67.40	91.34	
43	95	38.24	55.81	
43	96	22.85	39.92	
43	97	15.86	23.41	
43	98	12.00	21.40	
43	99	10.02	13.06	6.06 ± 0.61
44	95	71.05	74.65	
44	96	48.70	49.39	
44	97	36.48	41.26	
44	98	22.92	20.26	
44	99	18.36	18.56	
44	100	9.786	6.914	
44	101	10.18	8.621	
44	102	3.641	1.926	6.46 ± 0.82
44	103	4.790	3.297	
44	104	1.167	0.438	3.12 ± 0.31
44	105	2.049	1.033	
44	106	0.633	0.162	
45	99	32.59	45.95	
45	100	25.51	43.05	
45	101	14.47	20.28	
45	102	12.30	21.33	
45	103	6.907	9.088	
45	105	2.850	3.214	
46	100	47.11	48.48	
46	101	42.15	48.57	
46	102	21.14	19.41	
46	103	22.87	24.43	
46	104	9.134	7.071	
46	105	10.56	9.924	
46	106	3.595	2.180	5.28 ± 0.53
46	107	5.729	4.550	
46	108	1.932	0.898	2.73 ± 0.27
46	109	3.055	1.893	
46	110	0.869	0.294	
46	112	0.297	0.0684	
47	103	40.31	56.64	
47	104	31.92	52.94	
47	105	17.16	25.01	
47	107	7.217	9.774	
47	109	3.920	4.783	
47	111	2.295	2.341	
47	112	2.261	2.988	
47	113	1.132	0.878	
48	106	24.90	24.42	
48	107	22.77	25.82	
48	108	11.78	9.711	
48	109	12.43	12.71	
48	110	4.590	3.036	
48	111	6.322	5.178	
48	112	2.361	1.179	2.54 ± 0.36
48	113	3.477	2.259	
48	114	1.032	0.367	0.889± 0.089
48	115	1.737	0.839	
48	116	0.309	0.0755	
48	117	0.759	0.254	
49	109	22.44	32.71	
49	110	18.78	33.34	
49	111	9.269	13.19	
49	113	4.298	5.508	4.45 ± 0.47
49	115	1.953	2.112	2.39 ± 0.24
50	110	50.20	51.72	
50	112	18.99	17.12	44.9 ± 10.0
50	113	15.53	16.52	
50	114	6.601	4.763	
50	115	7.487	6.225	

Table 4 continued

50	116	2.495	1.346	1.88 ± 0.24
50	117	3.725	2.550	2.45 ± 0.19
50	118	1.229	0.478	1.18 ± 0.12
50	119	1.755	0.926	0.999± 0.087
50	120	0.467	0.127	0.450± 0.045
50	121	0.821	0.305	
50	122	0.0693	0.0123	0.221± 0.024
50	123	0.190	0.0472	
50	124	0.0160	0.00176	0.079± 0.013
50	125	0.0349	0.00540	
51	117	6.742	12.08	
51	119	3.283	5.378	
51	121	1.500	2.136	
51	122	1.717	3.271	
51	123	0.668	0.757	
51	124	0.775	1.208	
51	125	0.243	0.210	
51	126	0.313	0.378	
51	127	0.0779	0.0501	
51	128	0.116	0.106	
51	129	0.0228	0.0107	
52	116	50.03	60.17	
52	117	45.65	68.22	
52	118	26.00	28.08	
52	119	27.81	38.87	
52	120	12.26	10.89	
52	121	16.28	18.92	
52	122	6.105	4.259	
52	123	8.996	8.380	
52	124	3.082	1.635	
52	125	5.035	3.852	
52	126	1.734	0.711	1.88 ± 0.38
52	127	2.910	1.753	
52	128	0.930	0.292	
52	129	1.588	0.736	
52	130	0.505	0.118	
52	132	0.351	0.0632	
53	120	32.34	75.04	
53	121	17.03	29.39	
53	123	7.846	12.36	
53	124	8.378	17.07	
53	125	4.314	5.940	
53	126	4.933	9.061	
53	127	2.512	2.962	
53	129	1.606	1.572	
53	130	2.019	2.738	
53	131	1.021	0.809	
53	132	1.289	1.375	
53	133	0.607	0.372	
53	135	0.783	0.199	
54	122	19.55	19.82	
54	123	26.30	32.85	
54	124	10.46	9.186	
54	125	14.09	16.06	
54	126	5.885	4.340	
54	127	8.175	7.987	
54	128	3.490	2.090	
54	129	5.179	4.264	
54	130	2.169	1.022	
54	131	3.092	2.085	
54	132	1.324	0.486	
54	133	1.856	0.965	
54	134	0.896	0.267	
54	135	1.017	0.390	
54	136	0.882	0.120	
55	127	8.711	14.74	
55	129	5.272	8.383	
55	131	3.245	4.647	
55	132	3.572	6.789	
55	133	2.017	2.477	1.43 ± 0.27
55	134	2.310	3.671	
55	135	1.258	1.260	
55	136	1.394	1.644	
55	137	1.522	0.721	
56	126	23.53	25.69	
56	128	13.59	13.24	
56	129	17.91	23.20	
56	130	8.012	6.800	
56	131	11.04	12.13	
56	132	4.776	3.318	
56	133	6.646	6.216	
56	134	3.268	1.818	
56	135	4.483	3.406	5.58 ± 1.53
56	136	2.024	0.931	
56	137	2.429	1.386	2.96 ± 0.83
56	138	2.418	0.558	2.32 ± 0.23
56	139	6.488	2.830	
56	140	1.911	0.761	
57	132	11.83	27.42	
57	133	6.891	12.12	
57	135	4.006	6.345	
57	137	2.456	3.507	
57	138	2.509	4.054	
57	139	2.993	2.306	1.98 ± 0.20
57	140	5.547	7.717	
57	141	1.854	2.434	
57	142	1.470	2.176	
58	132	16.33	17.23	
58	133	21.95	29.60	
58	134	9.682	8.927	
58	135	12.63	14.58	
58	136	5.937	4.584	
58	137	7.586	7.742	
58	138	3.627	2.386	
58	139	4.404	3.506	
58	140	3.583	1.294	
58	141	9.619	6.136	
58	142	3.016	1.700	5.97 ± 0.60
58	143	2.883	1.956	
58	144	1.809	0.702	
59	137	7.978	14.43	
59	139	4.582	7.920	
59	141	4.260	4.583	
59	142	7.597	13.70	
59	143	31.07	52.67	
59	145	2.293	3.036	
60	138	12.55	12.47	
60	140	7.430	6.449	
60	141	7.915	8.209	
60	142	6.145	3.258	5.58 ± 0.56
60	143	13.61	11.43	
60	144	5.359	4.002	4.05 ± 0.57
60	145	5.169	4.732	
60	146	3.389	1.797	3.42 ± 0.34
60	147	3.459	2.632	
60	148	1.654	0.707	1.56 ± 0.33
60	149	1.975	1.145	
60	150	0.628	0.193	
61	143	6.809	9.055	
61	144	11.41	23.40	
61	145	4.887	9.778	
61	146	4.281	10.68	
61	147	3.651	6.211	
61	148	2.861	6.268	
61	149	1.877	2.824	
61	150	1.646	3.346	
61	151	0.887	0.935	
62	142	12.77	13.48	
62	144	10.39	7.384	
62	145	26.97	28.82	
62	146	8.518	8.054	
62	147	8.585	10.13	
62	148	5.419	4.133	
62	149	6.011	6.114	

Table 4 continued

62 150	3.069	1.833	3.12 ± 0.34
62 151	3.246	3.076	
62 152	1.128	0.529	1.81 ± 0.23
62 153	1.362	0.808	
62 154	0.461	0.163	0.833± 0.083
62 156	0.345	0.0882	
63 145	13.23	20.19	
63 146	18.91	41.40	
63 147	8.900	19.74	
63 148	7.215	19.89	
63 149	5.558	11.30	
63 150	4.862	12.91	
63 151	3.542	6.641	2.27 ± 1.27
63 152	2.657	6.655	
63 153	1.343	1.830	1.56 ± 0.16
63 154	1.590	2.466	
63 155	0.964	0.932	
63 156	0.968	1.007	
63 157	0.826	0.597	
64 146	18.41	16.16	
64 147	33.65	42.69	
64 148	13.77	15.92	
64 149	14.53	20.65	
64 150	9.331	9.182	
64 151	9.682	12.30	
64 152	5.099	4.144	
64 153	5.360	6.496	
64 154	1.960	1.262	
64 155	2.808	2.347	
64 156	1.074	0.567	3.84 ± 1.91
64 157	1.504	0.963	
64 158	0.773	0.321	1.84 ± 0.47
64 159	0.822	0.433	
64 160	0.426	0.138	
65 147	28.47	49.86	
65 148	37.36	89.06	
65 149	16.70	42.48	
65 150	13.68	39.88	
65 151	10.26	25.03	
65 152	8.775	26.39	
65 153	5.687	12.40	
65 154	4.358	12.52	
65 155	2.388	4.040	
65 156	2.946	5.944	
65 157	1.742	2.344	
65 158	1.992	3.116	
65 159	1.505	1.637	2.22 ± 0.29
65 160	1.306	1.745	
65 161	0.921	0.821	
66 152	17.89	20.77	
66 153	17.28	26.58	
66 154	8.985	8.907	
66 155	9.126	13.26	
66 156	4.048	3.474	
66 157	5.195	5.789	
66 158	2.389	1.794	
66 159	3.197	2.994	
66 160	1.776	1.102	
66 161	1.964	1.601	
66 162	1.006	0.530	1.93 ± 0.34
66 163	1.035	0.624	
66 164	0.593	0.218	1.11 ± 0.30
66 165	0.527	0.254	
66 166	0.272	0.0839	
67 161	2.848	4.480	
67 163	1.763	2.383	
67 165	1.380	1.394	0.763± 0.076
67 166	0.970	1.152	
67 167	0.668	0.560	
68 158	7.412	7.860	
68 160	6.025	5.703	
68 161	6.676	8.396	
68 162	3.792	3.216	
68 163	4.452	4.988	
68 164	2.375	1.769	
68 165	2.639	2.594	
68 166	1.596	0.970	
68 167	1.602	1.175	
68 168	0.907	0.448	1.66 ± 0.26
68 169	0.783	0.467	
68 170	0.499	0.194	0.613± 0.097
68 171	0.454	0.205	
68 172	0.303	0.0841	
69 163	4.640	9.177	
69 165	3.411	6.057	
69 166	3.394	7.709	
69 167	2.377	3.634	
69 168	2.288	4.037	
69 169	1.722	2.202	1.50 ± 0.13
69 170	1.300	1.834	
69 171	1.032	1.037	
69 172	0.701	0.753	
69 173	0.588	0.448	
70 164	7.180	7.380	
70 166	4.678	4.389	
70 168	3.008	2.538	
70 169	3.589	3.781	
70 170	2.342	1.781	
70 171	2.106	1.940	
70 172	1.296	0.808	1.68 ± 0.33
70 173	1.058	0.758	
70 174	0.745	0.351	1.16 ± 0.14
70 175	0.632	0.368	
70 176	0.457	0.174	0.547± 0.120
70 177	0.342	0.149	
70 178	0.178	0.0416	
71 169	3.862	7.524	
71 170	4.233	9.833	
71 171	3.149	5.641	
71 172	2.715	5.831	
71 173	2.299	3.633	
71 174	1.753	3.101	
71 175	1.672	2.159	
71 176	1.185	1.750	2.23 ± 0.55
71 177	1.044	1.192	
71 179	0.490	0.403	
72 170	5.588	5.902	
72 171	6.755	9.357	
72 172	4.367	4.254	
72 173	4.126	5.025	
72 174	2.872	2.538	
72 175	2.977	3.266	
72 176	2.181	1.630	
72 177	2.039	1.857	
72 178	1.464	0.933	1.86 ± 0.37
72 179	1.039	0.781	
72 180	0.778	0.359	0.848± 0.151
72 181	0.755	0.407	
72 182	0.438	0.159	
72 183	0.316	0.140	
72 184	0.198	0.0560	
73 173	5.303	11.74	
73 174	5.075	13.39	
73 175	3.817	7.592	
73 176	3.431	8.582	
73 177	3.043	5.317	
73 179	1.981	2.847	
73 180	1.288	2.033	
73 181	1.181	1.244	0.644± 0.064
73 182	0.869	1.053	
73 183	0.868	0.792	
73 184	0.506	0.541	
74 176	5.531	5.687	
74 177	5.255	6.994	

Table 4 continued

74 178	3.347	3.157	
74 180	2.065	1.595	
74 181	1.682	1.599	
74 182	1.140	0.666	
74 183	1.113	0.814	
74 184	0.799	0.396	0.789± 0.079
74 185	0.626	0.391	
74 186	0.445	0.162	0.542± 0.054
74 187	0.308	0.138	
74 188	0.169	0.0415	
75 181	2.796	4.965	
75 182	2.107	4.579	
75 183	1.756	2.453	
75 184	1.538	2.695	
75 185	1.211	1.537	1.41 ± 0.50
75 186	0.893	1.405	
75 187	0.655	0.678	0.529± 0.053
75 188	0.503	0.624	
75 189	0.347	0.274	
76 181	5.978	9.142	
76 182	3.921	4.031	
76 183	3.643	4.853	
76 184	2.450	2.182	
76 185	2.653	3.057	
76 186	1.592	1.228	
76 187	1.323	1.297	
76 188	0.850	0.483	
76 189	0.840	0.627	
76 190	0.415	0.170	0.678± 0.085
76 191	0.383	0.198	
76 192	0.125	0.0317	
76 193	0.136	0.0452	
76 194	0.0507	0.00885	
77 184	5.454	15.43	
77 185	3.765	7.838	
77 186	4.073	11.49	
77 187	2.692	5.325	
77 188	2.021	4.787	
77 189	1.451	2.219	
77 190	1.150	2.335	
77 191	0.713	0.877	0.828± 0.437
77 192	0.559	0.868	
77 193	0.321	0.300	
77 194	0.227	0.249	
77 195	0.123	0.0866	
78 185	9.764	16.77	
78 186	6.285	7.262	
78 187	6.969	11.64	
78 188	3.608	3.634	
78 189	3.776	5.107	
78 190	1.964	1.458	
78 191	2.084	2.268	
78 192	0.916	0.529	
78 193	1.075	0.853	
78 194	0.433	0.187	1.19 ± 0.20
78 195	0.591	0.325	
78 196	0.220	0.0691	0.560± 0.096
78 197	0.266	0.108	
78 198	0.0817	0.0183	
78 200	0.0330	0.00512	
78 202	0.0126	0.00138	
79 175	63.19	139.4	
79 191	2.366	4.083	
79 192	2.084	4.659	
79 193	1.135	1.638	
79 194	1.093	1.948	
79 195	0.572	0.653	
79 196	0.572	0.786	
79 197	0.309	0.272	0.373± 0.037
79 198	0.245	0.245	
79 199	0.140	0.0922	
80 192	2.521	2.184	
80 193	3.223	3.835	
80 194	1.253	0.912	
80 195	1.746	1.730	
80 196	0.769	0.454	
80 197	0.944	0.721	
80 198	0.339	0.163	
80 199	0.408	0.231	
80 200	0.170	0.0620	0.461± 0.461
80 201	0.189	0.0897	
80 202	0.0687	0.0199	
80 203	0.0862	0.0313	
80 204	0.0306	0.00616	
81 195	1.919	3.667	
81 196	1.860	4.485	
81 197	1.192	2.028	
81 198	1.160	2.379	
81 199	0.676	0.977	
81 200	0.612	1.022	
81 201	0.445	0.512	
81 202	0.334	0.441	
81 203	0.249	0.221	
81 204	0.156	0.150	
81 205	0.127	0.0801	0.519± 0.082
82 198	2.371	2.411	
82 199	2.755	3.714	
82 200	1.545	1.335	
82 201	1.566	1.719	
82 202	1.206	0.859	
82 203	0.869	0.761	
82 204	0.470	0.263	0.722± 0.082
82 205	0.406	0.274	
82 206	0.199	0.0853	0.556± 0.056
82 207	0.299	0.125	0.366± 0.033
82 208	0.722	0.125	0.395± 0.075
82 209	0.467	0.190	
82 210	0.194	0.0796	
82 212	0.111	0.0350	
83 201	2.903	7.515	
83 202	2.914	9.715	
83 203	1.893	4.572	
83 204	1.550	4.752	
83 205	1.239	2.800	
83 206	0.912	2.551	
83 207	0.745	1.660	
83 208	0.579	1.400	
83 209	0.949	1.160	0.590± 0.059
83 210	1.344	3.154	
83 212	0.408	1.360	
84 204	5.274	7.198	
84 205	6.624	11.91	
84 206	3.617	4.678	
84 207	4.035	6.725	
84 208	2.714	3.324	
84 209	2.781	3.821	
84 210	4.631	3.471	

References

[1] A.J. Koning, S. Hilaire, S. Goriely, TALYS-1.6. A nuclear reaction program, http://www.talys.eu/

[2] C.H.M. Broeders, A.Yu. Konobeyev, Semi-Empirical Systematics of (n,p) *R*eaction Cross-Section at 14.5, 20, and 30 MeV, *Nucl. Phys.* A780 (2006) 130.

[3] A.Yu. Konobeyev, U. Fischer, C.H.M. Broeders, Improved Systematics of (n,α) Reaction Cross-Section at 14.5 MeV, *Appl. Rad. Isotop.* 67 (2009) 357.

[4] C.H.M. Broeders, A.Yu. Konobeyev, "Systematics of (p,α) (p,nα), and (p,np) Reaction Cross-Sections", *Appl. Rad. Isotop.* 65 (2007) 1249.

[5] A.Yu. Konobeyev, U. Fischer, A.J. Koning, H. Leeb, S. Leray, Y. Yariv, What can we expect from the use of nuclear models implemented in MCNPX at projectile energies below 150 MeV? Detailed comparison with experimental data, *J. Korean Phys. Soc.* 59 (2011) 927.

KIT Scientific Working Papers
ISSN 2194-1629