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ESTABLISHMENT OF THE BOSPOR-80 MACHINE LIBRARY OF EVALUATED THRESHOLD REACTION CROSS-SECTIONS AND ITS TESTING BY MEANS OF INTEGRAL EXPERIMENTS

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A paper was published in 1979 containing a compilation of experimental data on the cross-sections of (n,p), (n,α) and (n,2n) threshold reactions and recommended excitation functions [1]. A further paper considered the development of evaluation methods based on the use of theoretical model calculations, an increase in the number of recommended excitation functions, correction of the recommended cross-sections on the basis of integral experiments and allowance for recent experimental data. To satisfy the wide circle of users, BOSPOR-80 - a machine library of evaluated threshold reaction cross-sections - was set up.

General information on the Library

The Library contains 142 recommended excitation functions for the (n,2n), (n,p), (n,α) and (n,t) reactions in the incident neutron energy range from threshold up to 20 MeV at intervals of 0.1 MeV. The cross-sections were evaluated after a critical analysis of existing experimental data and calculations based on up-to-date models of the nuclear reactions had been made.

In the analysis of the experimental data, preference was given to studies using radiochemical methods, enriched isotopes and semiconductor detectors which gave results coinciding to within the experimental error limits. Data differing substantially from the results of other authors which were in agreement were excluded from the study.

There are clearly insufficient experimental data to perform a reliable evaluation of the excitation functions for neutron-induced threshold reactions. Furthermore, the data from different authors often differ much more than the measurement errors quoted. Calculations were therefore used to obtain recommended cross-sections: in the first place, this allowed results which were obviously erroneous to be excluded from the overall set of experimental data; secondly, it enabled reaction cross-sections to be evaluated for those incident neutron energy ranges and target nucleus mass numbers for which no experimental data exist. The cross-sections were evaluated on the basis of the optical and statistical models and Griffin's pre-equilibrium decay model. Predictions from the (N-Z) systematics were taken into account in analysing the cross-sections of reactions induced by 14-15 MeV neutrons. The methodology used to evaluate the threshold reaction cross-sections has been described in detail elsewhere [1-8].

In order to correct and verify further the accuracy of the recommended threshold reaction excitation functions given in the Library, they were compared with the results of integral experiments in two ways:

- A comparative analysis of recommended microscopic cross-sections for $^{56}Fe(n,p)^{56}Mn$ and $^{58}Ni(n,p)^{58}Co$ using data from three libraries (ENDF/B-IV, UKNDL and BOSPOR-80) based on one of the methods of unfolding neutron spectra from measured reaction rates (the BOSPOR-80 data can be recommended for practical application) [9]; and
- A comparison of experimental cross-sections measured in the fission spectrum with values obtained by averaging the excitation functions in the BOSPOR-80 Library over the ^{235}U fission spectrum (in specific cases, microscopic cross-sections in the near-threshold range of incident neutron energies were corrected in accordance with the integral data results).

The results of this comparison are described in detail below.

<u>Threshold reaction cross-sections averaged over the ^{235}U fission spectrum</u>

The BOSPOR-80 excitation functions were averaged over the ^{235}U thermal fission spectrum for comparison with cross-sections measured in the fission spectrum.

The fission neutron spectrum was approximated by the Watt, Cranberg and Leachman formulas [10]:

$$X_1(E) = 0{,}48395\,\exp(-E)\sin h\sqrt{2E}; \qquad (I)$$

$$X_2(E) = 0{,}45274\,\exp(-E/0{,}965)\sin h\sqrt{2{,}29E}; \qquad (2)$$

$$X_3(E) = 0{,}76985\,\exp(-0{,}775E)\sqrt{E}. \qquad (3)$$

The differences between the spectra approximated by these formulas are shown in Figs 1 and 2. The uncertainty in the description of the fission neutron spectrum reflects the current status of experimental data, the greatest uncertainty being observed in the very soft and hard parts of the spectrum.

The excitation functions of the (n,p), (n,α) and (n,2n) reactions for comparatively light (^{45}Sc, Fig. 3a) and heavy (^{197}Au, Fig. 3b) isotopes are examined for the purpose of illustration. Comparing the threshold reaction excitation functions with the shape of the fission spectrum, we can predict the main tendencies in the integral cross-sections:

- The threshold region of the excitation function makes a decisive contribution to the integral cross-sections since the number of fission neutrons decreases exponentially with increasing energy;
- The integral cross-sections of the (n,p) and (n,α) reactions decrease from light to heavy isotopes as a result of the growth of the Coulomb barrier; and
- The integral cross-sections of the (n,2n) reaction increase for heavy nuclei as a result of the reduction in the neutron binding energy.

The table compares the averaged cross-sections with the integral experiments. The evaluated experimental data are taken from Refs [11-16].

A comparison of the calculated and experimental data does not allow any definite conclusion to be drawn regarding the applicability of one particular formula for approximating the spectrum, although broadly speaking it can be said that formula (1) gives the best results for the cross-sections of the (n,p) and (n,α) reactions, while an analysis of the (n,2n) reaction cross-sections suggests that the fission neutron spectrum here is if anything somewhat harder - closer to formula (3). The mean square deviation from the evaluated experimental data of the BOSPOR-80 cross-sections averaged over the spectrum given by formula (1) is approximately 25%.

It is interesting to compare the fission-spectrum-averaged cross-sections obtained for the BOSPOR-80 excitation functions with the results of various semi-empirical evaluations. The table below gives the average cross-sections obtained by Pearlstein [17] and Calamand's predictions [12] based on Roy and Hawton's classification. The excitation functions of the (n,p), (n,α) and (n,2n) reactions were calculated by Pearlstein by a semi-empirical method, and averaging was performed over the Cranberg spectrum. On the whole, the data of Pearlstein and Calamand are in poorer agreement with the experimental cross-sections than the BOSPOR-80 values, which were obtained by a more rigorous method. The satisfactory agreement between Pearlstein's predictions for the spectrum-averaged cross-sections of the (n,2n) reaction with the data given in the present paper should be pointed out. The mean square deviation from the BOSPOR-80 cross-sections is about 33%. With the exception of some predictions in the region of the relatively light elements (^{14}N, ^{19}F, ^{31}P, ^{32}S, ^{35}Cl, ^{39}K, ^{50}Cr, ^{54}Fe, ^{58}Ni) which deviate considerably, Calamand's calculations of the (n,2n) reaction cross-sections [12] show a mean square deviation of approximately 43% from the BOSPOR-80 spectrum-averaged cross-sections approximated by formula (1). Calamand's predictions of average cross-sections for the (n,α) and (n,p) reactions [12] show a mean square deviation from the BOSPOR-80 data of about 150 and 200% respectively. In this last example, the cross-sections for ^{6}Li and ^{24}Mg were not taken into account.

The evaluated data have been organized in the form of a machine library recorded on magnetic tape in the EC-1033 computer of the Nuclear Data Centre (Obninsk) and can be obtained on request. The BOSPOR-80 microscopic cross-sections were entered in the SAIPS data computing system [18]. We intend to continue work on the Library both to increase the number of reactions considered and to refine the recommended cross-sections further, taking into account new differential and integral measurements.

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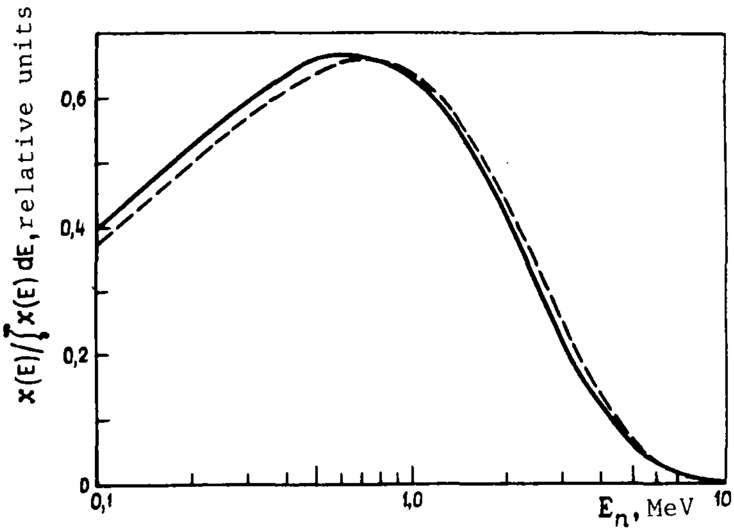

Fig. 1. ^{235}U fission neutron spectrum, approximated by formulas (1), (2) (-----) and (3) (———).

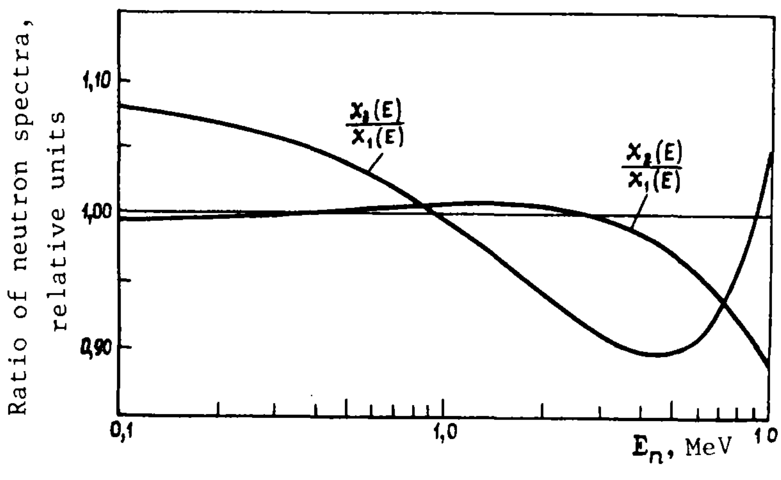

Fig. 2. Relative deviations of neutron spectra represented by formulas (1) [$\chi_1(E)$], (2) [$\chi_2(E)$] and (3) [$\chi_3(E)$].

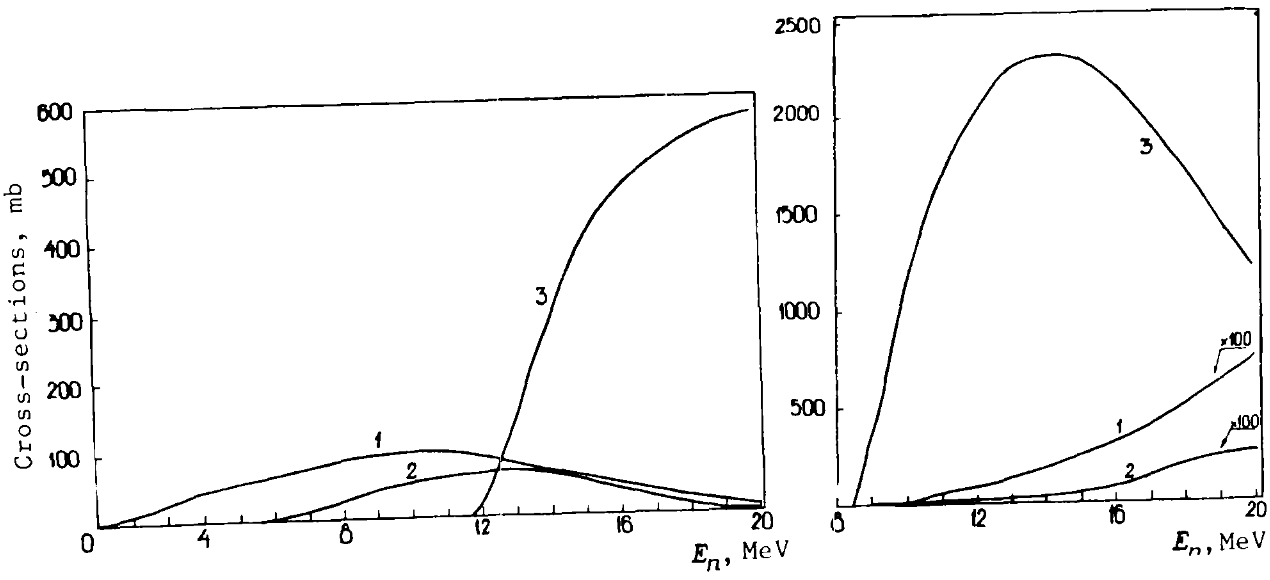

Fig. 3. Excitation functions of the reactions: 1-(n,p), 2-(n,α), 3-(n,2n) for the isotopes ^{45}Sc(a) and ^{197}Au(b).

Comparison of the BOSPOR-80 excitation functions averaged over the ^{235}U fission neutron spectrum with the experimental data and the calculations of Pearlstein [17] and Calamand [12]

Serial number	Reaction	Cross-sections averaged over the ^{235}U thermal fission neutron spectrum, mb					
		Experiment	BOSPOR-80			[17]	[12]
			Watt	Cranberg	Leachman		
1	$^{2}H(n,2n)^{1}H$	-	5,41	5,17	5,19	-	-
2	$^{6}Li(np)^{6}He$	-	4,18	4,09	3,91	-	39
3	$^{6}Li(n2n)^{5}Li$	-	0,158	0,142	0,173	-	2,1
4	$^{9}Be(n2n)^{8}Be$	144±6	143	140	135	-	250
5	$^{10}B(nt)$	-	23,8	23,4	22,6	-	-
6	$^{12}C(np)^{12}B$	-	$0,26\cdot10^{-3}$	$0,2\cdot10^{-3}$	$0,47\cdot10^{-3}$	-	$<0,1\cdot10^{-3}$
7	$^{14}N(n\alpha)^{11}B$	-	91,0	90,2	86	-	25
8	$^{14}N(n2n)^{13}N$	-	$0,94\cdot10^{-3}$	$0,77\cdot10^{-3}$	$1,3\cdot10^{-2}$	-	0,03
9	$^{16}O(np)^{16}N$	0,019±0,001	0,019	0,016	0,024	-	0,0005
10	$^{16}O(n\alpha)^{13}C$	-	11,3	11,0	10,7	-	6,0
11	$^{19}F(np)^{19}O$	0,83±0,02	1,18	1,12	1,15	-	0,23
12	$^{19}F(n\alpha)^{16}N$	15,1 ±0,2	14,3	13,8	13,4	-	8,0
13	$^{19}F(n2n)^{18}F$	$(7,3\pm0,7)\cdot10^{-3}$	$7,7\cdot10^{-3}$	$6,3\cdot10^{-3}$	$1,1\cdot10^{-2}$	-	$50\cdot10^{-3}$
14	$^{23}Na(np)^{23}Ne$	1,43±0,02	1,39	1,31	1,36	-	0,31
15	$^{23}Na(n,\alpha)^{20}F$	0,53±0,02	0,556	0,502	0,591	-	0,49
16	$^{23}Na(n2n)^{22}Na$	$(2,2\pm0,2)\cdot10^{-3}$	$4\cdot10^{-3}$	$3,15\cdot10^{-3}$	$6,38\cdot10^{-3}$	$2,39\cdot10^{-3}$	$8\cdot10^{-3}$
17	$^{24}Mg(np)^{24}Na$	1,48±0,082	1,52	1,4	1,56	-	62
18	$^{27}Al(np)^{27}Mg$	3,86±0,25	3,99	3,82	3,83	-	3,1
19	$^{27}Al(n\alpha)^{24}Na$	0,705±0,040	0,698	0,633	0,724	-	0,48
20	$^{28}Si(np)^{28}Al$	6,4±0,8	7,55	7,08	7,44	-	2,0
21	$^{31}P(np)^{31}Si$	35,5±2,7	32,5	32,0	30,6	-	11,0
22	$^{31}P(n\alpha)^{28}Al$	1,9±0,6	1,95	1,81	1,94	-	1,1
23	$^{31}P(n2n)^{30}P$	-	$1,09\cdot10^{-3}$	$0,859\cdot10^{-3}$	$1,69\cdot10^{-3}$	$0,36\cdot10^{-3}$	0,013
24	$^{32}S(np)^{32}P$	66,8±3,7	65,6	64,5	61,9	-	100
25	$^{32}S(n\alpha)^{29}Si$	-	43,6	42,8	41,2	-	13
26	$^{32}S(nt)^{30}P$	-	$1,06\cdot10^{-5}$	$0,8\cdot10^{-5}$	$1,8\cdot10^{-5}$	-	-
27	$^{32}S(n2n)^{31}S$	-	$0,63\cdot10^{-5}$	$0,48\cdot10^{-5}$	$1,18\cdot10^{-5}$	-	$8\cdot10^{-4}$
28	$^{34}S(n\alpha)^{31}Si$	2,2±0,2	2,3	2,14	2,29	-	13
29	$^{25}Cl(n\alpha)^{32}P$	8,8±4,6	10,7	10,3	10,2	-	8,0
30	$^{35}Cl(n2n)^{34}Cl$	-	$0,79\cdot10^{-3}$	$0,62\cdot10^{-3}$	$1,25\cdot10^{-3}$	$0,34\cdot10^{-3}$	0,01
31	$^{35}Cl(n2n)^{34m}Cl$	-	$0,51\cdot10^{-3}$	$0,4\cdot10^{-3}$	$0,8\cdot10^{-3}$	-	-
32	$^{39}K(np)^{39}Ar$	-	82,2	81,1	78	-	20
33	$^{39}K(n\alpha)^{36}Cl$	8,0±0,3	5,46	5,24	5,24	-	13
34	$^{39}K(n2n)^{38}K$	-	$0,37\cdot10^{-3}$	$0,29\cdot10^{-3}$	$0,6\cdot10^{-3}$	$0,28\cdot10^{-3}$	$7\cdot10^{-3}$
35	$^{41}K(np)^{41}Ar$	2,1±0,2	2,21	2,12	2,12	-	1,1
36	$^{41}K(n\alpha)^{38}Cl$	0,76±0,05	0,56	0,53	0,55	-	2,6
37	$^{42}Ca(np)^{42}K$	-	3,44	3,25	3,35	-	2,6
38	$^{44}Ca(np)^{44}K$	-	0,071	0,064	0,077	-	0,11
39	$^{44}Ca(n\alpha)^{41}Ar$	0,061±0,009	0,055	0,049	0,061	0,18	0,033
40	$^{45}Sc(np)^{45}Ca$	15±12	14,4	14,2	13,7	14	22,0
41	$^{45}Sc(n\alpha)^{42}K$	0,182±0,012	0,407	0,373	0,42	-	0,67
42	$^{45}Sc(n2n)^{44}Sc$	-	0,04	0,033	0,057	0,039	0,05
43	$^{45}Sc(n2n)^{44m}Sc$	-	0,012	0,0099	0,018	-	-
44	$^{46}Ti(np)^{46}Sc$	12,5±0,9	12,8	12,3	12,3	11	12,0
45	$^{46}Ti(n2n)^{45}Ti$	$(7,8\pm0,9)\cdot10^{-3}$	$3,7\cdot10^{-3}$	$2,9\cdot10^{-3}$	$6,1\cdot10^{-3}$	$2,0\cdot10^{-3}$	$8\cdot10^{-3}$
46	$^{47}Ti(np)^{47}Sc$	19,0±1,4	22,2	21,8	21,0	29	11,0
47	$^{48}Ti(np)^{48}Sc$	0,300±0,018	0,262	0,241	0,269	0,28	0,98
48	$^{49}Ti(np)^{49}Sc$	-	0,47	0,45	0,45	1,2	1,4
49	$^{50}Ti(np)^{50}Sc$	-	0,0085	0,0073	0,01	0,025	0,013
50	$^{51}V(n,\alpha)^{48}Sc$	0,022±0,003	0,023	0,0204	0,0257	0,017	0,024

Serial number	Reaction	Cross-sections averaged over the ^{235}U thermal fission neutron spectrum, mb					
		Experiment	BOSPOR-80			[17]	[12]
			Watt	Cranberg	Leachman		
51	^{50}Cr(n2n)^{49}Cr	$(6\pm1)\cdot10^{-3}$	$1,8\cdot10^{-3}$	$1,4\cdot10^{-3}$	$2,8\cdot10^{-3}$	$1,6\cdot10^{-3}$	0,011
52	^{52}Cr(n,p)^{52}V	1,09±0,08	0,76	0,71	0,78	0,76	0,66
53	^{52}Cr(n2n)^{51}Cr	-	0,033	0,027	0,048	0,041	0,028
54	^{55}Mn(n2n)^{54}Mn	0,244±0,015	0,231	0,193	0,300	0,180	0,18
55	^{54}Fe(np)^{54}Mn	79,7±4,9	82,2	80,4	77,7	72	70
56	^{54}Fe(nα)^{51}Cr	0,6±0,2	0,604	0,559	0,614	0,79	0,49
57	^{54}Fe(n2n)^{53}Fe	0,005±0,0025	$1,4\cdot10^{-3}$	$1,08\cdot10^{-3}$	$2,4\cdot10^{-3}$	$1,6\cdot10^{-3}$	0,007
58	^{56}Fe(np)^{56}Mn	1,035±0,075	1,08	1,00	1,08	0,96	0,81
59	^{56}Fe(n2n)^{55}Fe	-	0,0754	0,0617	0,105	0,065	0,068
60	^{59}Co(np)^{59}Fe	1,42±0,14	1,14	1,08	1,10	3,1	1,0
61	^{59}Co(nα)^{56}Mn	0,143±0,010	0,147	0,135	0,151	0,075	0,17
62	^{59}Co(n2n)^{58}Co	0,40±0,04	0,174	0,145	0,229	0,14	0,15
63	^{58}Ni(np)^{58}Co	108,5±5,4	103	101	97,9	96	85,0
64	^{59}Ni(nd)^{57}Co	-	0,172	0,155	0,184	0,12	-
65	^{58}Ni(nα)^{59}Fe	3±0,9	2,75	2,63	2,66	2,1	4,4
66	^{58}Ni(n2n)^{57}Ni	$(5,77\pm0,31)\cdot10^{-3}$	$2,6\cdot10^{-3}$	$2,0\cdot10^{-3}$	$3,85\cdot10^{-3}$	$3,3\cdot10^{-3}$	0,026
67	^{60}Ni(np)^{60}Co	2,3±0,4	2,57	2,42	2,53	1,7	2,1
68	^{62}Ni(nα)^{59}Fe	0,09±0,07	0,0289	0,0255	0,327	0,04	0,036
69	^{63}Cu(n2n)^{62}Cu	1,122±0,012	0,097	0,080	0,133	0,095	0,11
70	^{65}Cu(np)^{65}Ni	0,48±0,08	0,557	0,533	0,536	0,39	0,34
71	^{65}Cu(n2n)^{64}Cu	-	0,32	0,271	0,41	0,42	0,28
72	^{64}Zn(np)^{64}Cu	29,9±1,6	36,8	36,0	34,8	22	43
73	^{64}Zn(n2n)^{63}Zn	-	0,017	0,014	0,026	0,044	0,04
74	^{66}Zn(np)^{66}Cu	0,62±0,11	0,833	0,78	0,826	0,94	2,2
75	^{66}Zn(n2n)^{65}Zn	<5	0,118	0,099	0,161	0,22	0,091
76	^{69}Ga(n2n)^{68}Ga	-	0,227	0,189	0,299	0,32	0,20
77	^{71}Ga(n2n)^{70}Ga	-	0,617	0,527	0,758	0,67	0,56
78	^{70}Ge(n2n)^{69}Ge	1,8±0,9	0,073	0,060	0,104	0,096	0,059
79	^{76}Ge(n2n)^{75}Ge	-	0,66	0,57	0,81	0,75	0,51
80	^{75}As(np)^{75}Ge	0,45±0,15	0,232	0,22	0,23	0,44	0,67
81	^{75}As(nα)^{72}Ga	-	$7,1\cdot10^{-3}$	$6,1\cdot10^{-3}$	$8,2\cdot10^{-3}$	0,019	$6,3\cdot10^{-3}$
82	^{75}As(n2n)^{74}As	0,33±0,02	0,281	0,235	0,367	0,39	0,23
83	^{74}Se(n2n)^{73}Se	-	0,03	0,024	0,045	0,043	0,036
84	^{76}Se(n2n)^{75}Se	-	0,137	0,113	0,189	0,14	0,091
85	^{78}Se(n2n)^{77}Se	-	0,234	0,195	0,310	0,28	0,18
86	^{80}Se(n2n)^{79}Se	10	0,432	0,366	0,547	0,59	0,34
87	^{82}Se(n2n)^{81}Se	-	1,01	0,873	1,2	0,95	0,64
88	^{79}Br(n2n)^{78}Br	-	0,204	0,169	0,272	0,25	0,15
89	^{81}Br(n2n)^{80}Br	-	0,288	0,242	0,374	0,49	0,26
90	^{81}Br(n2n)^{81m}Br	-	0,168	0,14	0,221	-	-
91	^{85}Rb(n2n)^{84}Rb	0,37±0,01	0,27	0,22	0,35	0,3	0,20
92	^{87}Rb(n2n)^{86}Rb	-	0,372	0,313	0,476	1,8	0,35
93	^{84}Sr(n2n)^{83}Sr	-	0,1	0,08	0,15	0,064	0,042
94	^{88}Sr(n2n)^{87m}Sr	<10	0,0451	0,037	0,0626	-	-
95	^{89}Y(n2n)^{88}Y	0,156±0,011	0,126	0,103	0,177	0,49	0,076
96	^{90}Zr(np)^{90}Y	0,38±0,02	0,33	0,31	0,33	0,12	0,71

Serial number	Reaction	Cross-sections averaged over the ^{235}U thermal fission neutron spectrum, mb					
		Experiment	BOSPOR-80			[17]	[12]
			Watt	Cranberg	Leachman		
97	^{90}Zr(n2n)^{89}Zr	0,076±0,01	0,079	0,064	0,115	0,26	0,048
98	^{93}Nb(n2n)^{92}Nb	-	1,04	0,9	1,25	0,9	1,1
99	^{93}Nb(n2n)^{92m}Nb	0,475±0,032	0,39	0,33	0,46	-	-
100	^{92}Mo(n2n)^{91}Mo	-	0,015	0,012	0,024	0,0289	0,023
101	^{103}Rh(n2n)^{102}Rh	-	0,729	0,623	0,896	0,715	0,74
102	^{106}Cd(n2n)^{105m}Cd	-	0,132	0,108	0,182	-	-
103	^{111}Cd(np)^{111}Ag	-	0,020	0,018	0,023	-	0,083
104	^{112}Cd(nα)^{109}Pd	-	$0{,}7\cdot10^{-3}$	$0{,}69\cdot10^{-3}$	$0{,}58\cdot10^{-3}$	$0{,}9\cdot10^{-3}$	10^{-3}
105	^{116}Cd(n2n)^{115}Cd	-	2,07	1,81	2,4	1,51	1,5
106	^{113}In(n2n)^{112}In	-	0,731	0,622	0,909	0,704	0,7
107	^{115}In(n2n)^{114}In	-	1,07	0,922	1,3	1,05	1,1
108	^{115}In(n2n)^{114m}In	-	0,761	0,652	0,926	-	-
109	^{112}Sn(n2n)^{111}Sn	-	0,235	0,194	0,315	0,142	0,18
110	^{118}Sn(nα)^{115}Cd	-	$2{,}3\cdot10^{-4}$	$2\cdot10^{-4}$	$3\cdot10^{-4}$	-	$4\cdot10^{-4}$
111	^{121}Sb(n2n)^{120}Sb	-	0,846	0,724	1,04	0,883	0,89
112	^{123}Sb(n2n)^{122}Sb	-	1,0	0,86	1,2	1,16	1,2
113	^{127}I(n2n)^{126}I	1,05±0,065	1,13	0,973	1,36	0,965	1,0
114	^{133}Cs(n2n)^{132}Cs	-	0,992	0,851	1,21	1,00	1,2
115	^{140}Ce(n2n)^{139}Ce	-	1,32	1,14	1,57	1,15	1,0
116	^{140}Ce(n2n)^{135m}Ce	-	0,44	0,37	0,55	-	-
117	^{142}Ce(n2n)^{141}Ce	-	7,3	6,6	7,8	6,13	7,9
118	^{141}Pr(n2n)^{140}Pr	-	1,1	0,95	1,34	0,86	0,86
119	^{142}Nd(n2n)^{141}Nd	-	0,627	0,530	0,795	2,97	0,57
120	^{146}Nd(n2n)^{145}Nd	-	4,98	4,44	5,47	4,85	5,4
121	^{148}Nd(n2n)^{147}Nd	-	6,13	5,49	6,64	6,02	6,9
122	^{150}Nd(n2n)^{149}Nd	-	6,94	6,24	7,45	6,12	6,7
123	^{144}Sm(n2n)^{143}Sm	-	0,369	0,308	0,490	0,321	0,27
124	^{148}Sm(n2n)^{147}Sm	-	3,26	2,88	3,67	2,90	3,1
125	^{150}Sm(n2n)^{149}Sm	-	3,50	3,10	3,91	3,42	3,6
126	^{152}Sm(n2n)^{151}Sm	-	2,34	2,05	2,69	2,84	2,8
127	^{154}Sm(n2n)^{153}Sm	-	3,90	3,45	4,34	3,80	3,7
128	^{169}Tm(n2n)^{168}Tm	-	3,56	3,14	4,03	3,43	3,7
129	^{175}Lu(n2n)^{174}Lu	-	4,79	4,25	5,32	4,15	5,6
130	^{181}Ta(np)^{181}Hf	-	$1\cdot10^{-3}$	$0{,}8\cdot10^{-3}$	$1{,}3\cdot10^{-3}$	-	$3\cdot10^{-3}$
131	^{181}Ta(n2n)^{180}Ta	-	4,96	4,41	5,49	5,27	5,8
132	^{181}Ta(n2n)^{180m}Ta	-	2,63	2,34	2,91	-	-
133	^{191}Ir(n2n)^{190}Ir	-	2,71	2,38	3,1	3,03	3,8
134	^{193}Ir(n2n)^{192}Ir	-	3,71	3,28	4,17	4,59	5,4
135	^{197}Au(n2n)^{196}Au	3,0±3	3,23	2,84	3,69	3,32	4,0
136	^{203}Tl(n2n)^{202}Tl	3,0±0,5	3,08	2,71	3,49	4,82	5,8
137	^{205}Tl(n2n)^{204}Tl	-	3,78	3,34	4,24	5,61	7,0
138	^{204}Pb(n2n)^{203}Pb	2,45±0,4	2,06	1,79	2,41	3,07	3,0
139	^{208}Pb(n2n)^{207m}Pb	-	0,891	0,769	1,06	-	-
140	^{209}Bi(n2n)^{208}Bi	-	5,92	5,27	6,5	5,93	7,8
141	^{232}Th(n2n)^{231}Th	15,7±0,7	15,4	14,1	15,9	-	-
142	^{238}U(n2n)^{237}U	15,7±0,8	14,5	13,4	14,8	-	-

Note: In the opinion of the authors of the compilation, the underlined values are the most reliable.