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Central Scientific Research Institute of Information and Engineering-Economic Studies on Atomic Science and Technology

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Institute of Physics and Power Engineering

MEASUREMENT OF THE ^{240}Pu AND ^{242}Pu FISSION CROSS-SECTIONS RELATIVE TO THE ^{235}U CROSS-SECTION IN THE 0.127-7.4 MeV NEUTRON ENERGY RANGE

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(Paper submitted to Atomnaya Ehnergiya)

The fission cross-sections of ^{240}Pu and ^{242}Pu have been measured by a relative method for neutron energies of 0.127-7.4 MeV. The ^{235}U fission cross-section was used as a standard. The measurements were carried out on electrostatic accelerators with neutrons derived from the Li(p,n), T(p,n) and D(d,n) reactions. The fission fragments were detected by twin ionization chambers. The experimentally measured energy dependences of $\sigma_f(^{240}Pu)/\sigma_f(^{235}U)$ and $\sigma_f(^{242}Pu)/\sigma_f(^{235}U)$ (see Table 1) were then normalized over the entire energy range to the absolutely determined values of the ratios $\sigma_f(^{240}Pu)/\sigma_f(^{239}Pu)$ and $\sigma_f(^{242}Pu)/\sigma_f(^{239}Pu)$ (at neutron energies E_n of 0.975, 1.5, 2.0, 2.5 and 3.0 MeV), multiplied by the values $\sigma_f(^{239}Pu)/\sigma_f(^{235}U)$ = 1.443, 1.572, 1.154, 1.547 and 1.556 respectively, obtained in previous work by the present authors*/. Experimentally determined corrections for neutron scattering by the target structure and for the laboratory background and the background due to accompanying reactions were made to the measured values. A number of calculated corrections were also made to allow for fast-neutron-induced fission of minority isotopes, the neutron energy dependence of the ratio of the fission chamber efficiencies and the difference between the fast neutron fluxes through the layers.

The overall errors in the results are 2.1 and 2.3% for $\sigma_f(^{240}Pu)/\sigma_f(^{235}U)$ and $\sigma_f(^{242}Pu)/\sigma_f(^{235}U)$ and they increase towards the edges of the neutron energy range.

*/ FURSOV, B.I., KUPRIYANOV, V.M., SMIRENKIN, G.N., At. Ehnerg. 43 (1977).

Table 1. $^{240}Pu/^{235}U$ and $^{242}Pu/^{235}U$ fission cross-section ratios

No.	E_n, MeV	ΔE_n, keV	$\frac{\sigma_f\,^{240}Pu}{\sigma_f\,^{235}U}$	$\Delta\frac{\sigma_f\,^{240}Pu}{\sigma_f\,^{235}U}$, %	$\frac{\sigma_f\,^{242}Pu}{\sigma_f\,^{235}U}$	$\Delta\frac{\sigma_f\,^{242}Pu}{\sigma_f\,^{235}U}$, %
I	0,I27	I9	0,0534	4,8	0,0I00	5,7
2	0,I50	I9	0,0544	4,3	0,0I36	4,6
3	0,I80	I9	0,0574	3,6	0,0I59	5,3
4	0,2I0	I8	0,0639	3,8	0,0I93	5,3
5	0,240	I7	0,0696	3,9	0,0293	5,4
6	0,270	I8	0,08I7	3,6	0,03I0	4,9
7	0,300	I8	0,0898	3,6	0,040I	3,7
8	0,3I3	40	0,I07	3,3	0,0533	4,0
9	0,342	38	0,II9	2,6	0,0623	4,2
I0	0,365	37	0,I40	2,9	0,078I	3,5
II	0,404	36	0,I74	2,3	0,0958	3,0
I2	0,444	35	0,224	2,2	0,I30	2,6
I3	0,483	34	0,306	2,2	0,I73	2,3
I4	0,523	33	0,393	2,2	0,209	2,4
I5	0,562	33	0,498	2,2	0,284	2,5
I6	0,60I	32	0,598	2,2	0,359	2,3
I7	0,64I	32	0,695	2,2	0,428	2,3
I8	0,680	32	0,754	2,2	0,49I	2,5
I9	0,720	32	0,8I8	2,I	0,557	2,2
20	0,759	3I	0,905	2,2	0,670	2,3
2I	0,798	3I	0,976	2,I	0,78I	2,3
22	0,836	3I	I,060	2,2	0,88I	2,3
23	0,877	3I	I,I30	2,I	0,977	2,3
24	0,926	3I	I,I44	2,I	I,006	2,3
25	0,975	3I	I,I89	2,I	I,I04	2,2
26	I,025	34	I,243	2,I	I,I54	2,3
27	I,074	37	I,26I	2,I	I,I97	2,2

Continued

No.	E_n, MeV	ΔE_n, keV	$\frac{\sigma_f\,^{240}Pu}{\sigma_f\,^{235}U}$	$\Delta\frac{\sigma_f\,^{240}Pu}{\sigma_f\,^{235}U}$, %	$\frac{\sigma_f\,^{242}Pu}{\sigma_f\,^{235}U}$	$\Delta\frac{\sigma_f\,^{242}Pu}{\sigma_f\,^{235}U}$, %
28	I,I23	40	I,259	2,I	I,I99	2,2
29	I,I72	42	I,274	2,I	I,I87	2,2
30	I,22I	44	I,257	2,I	I,I6I	2,5
3I	I,270	45	I,270	2,I	I,I43	2,4
32	I,320	46	I,270	2,2	I,I38	2,2
33	I,400	47	I,268	2,I	I,I4I	2,3
34	I,500	48	I,275	2,0	I,I00	2,2
35	I,600	49	I,294	2,I	I,III	2,2
36	I,700	60	I,300	2,2	I,II3	2,2
37	I,800	6I	I,304	2,I	I,I23	2,2
38	I,900	63	I,296	2,I	I,I2I	2,2
39	2,00	60	I,3I4	2,0	I,I35	2,2
40	2,I0	68	I,309	2,0	I,I25	2,3
4I	2,20	70	I,3I6	2,0	I,I07	2,2
42	2,30	7I	I,3I8	2,0	I,I06	2,6
43	2,40	72	I,330	2,0	I,I00	2,2
44	2,50	73	I,352	2,0	I,I07	2,2
45	2,60	77	I,337	2,0	I,II9	2,3
46	2,70	78	I,336	2,0	I,I27	2,5
47	2,80	79	I,357	2,0	I,I44	2,2
48	2,90	82	I,363	2,0	I,I44	2,2
49	3,00	84	I,369	2,I	I,I48	2,2
50	3,I0	86	I,377	2,0	I,I59	2,2
5I	3,20	88	I,375	2,I	I,I53	2,2
52	3,30	9I	I,384	2,0	I,I53	2,2
53	3,40	93	I,380	2,0	I,I47	2,2
54	3,60	I92	I,383	2,0	I,I52	2,2
55	3,80	I82	I,382	2,0	I,I50	2,2
56	4,00	I46	I,397	2,I	I,I52	2,3
57	4,80	I4I	I,404	2,2	I,I45	2,2
58	4,40	I32	I,402	2,2	I,I47	2,2
59	4,60	I3I	I,394	2,2	I,I46	2,3
60	4,80	I25	I,403	2,2	I,I42	2,3
6I	5,00	I26	I,4I3	2,2	I,I47	2,2
62	5,20	I29	I,432	2,2	I,I56	2,6
63	5,40	I3I	I,450	2,2	I,I82	2,3
64	5,60	I35	I,468	2,3	I,209	2,3
65	5,80	I38	I,487	2,3	I,239	2,2
66	6,00	I42	I,488	2,3	I,279	2,3
67	6,20	I47	I,453	2,3	I,274	2,3
68	6,40	I52	I,406	2,4	I,273	2,4
69	6,60	I60	I,380	2,6	I,263	2,6
70	6,80	I67	I,344	2,5	I,226	2,8
7I	7,00	I73	I,330	2,5	I,I90	2,8
72	7,20	I78	I,305	2,6	I,I78	2,9
73	7,40	I83	I,283	2,8	I,I67	3,0

PHOTOFISSION YIELDS AND CROSS-SECTIONS OF Th, U, Np, Pu AND Am ISOTOPES IN THE 4.5-7.0 MeV ENERGY RANGE

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(Paper submitted to Voprosy Atomnoj Nauki i Tekhniki;
Seriya: Yadernye Konstanty)

A table is given of numerical data on photofission yields and cross-sections for nine nuclei (^{232}Th, ^{233}U, ^{235}U, ^{236}U, ^{238}U, ^{237}Np, ^{239}Pu, ^{241}Pu, ^{241}Am) at energies of 4.5-7.0 MeV. The data were obtained with a gamma-radiation Bremsstrahlung beam from an electron cyclotron. The results are given in the form of ratios of the photofission yields for the given nuclei to the ^{238}U yield and are compared with data from other authors.

Table 1

The photofission reaction yield Y(fiss. $mg^{-1}.\mu C^{-1}$) at a distance of 4.7 cm from decelerating the target and the photofission cross-section $\sigma_{\gamma f}$ (mb) (only random errors are shown)

Isotope		Experimental error, %	E_{max}, MeV	
			4,4	4,6
^{232}Th:	Y	I2	-	-
	$\sigma_{\gamma f}$	30	-	-
^{233}U:	Y	I0	-	-
	$\sigma_{\gamma f}$	30	-	-
^{235}U:	Y	I0	-	-
	$\sigma_{\gamma f}$	30	-	-
^{236}U:	Y	I0	I,08 ± 0,II (-5)	3,8I ± 0,I9 (-5)
	$\sigma_{\gamma f}$	30	4,22 ± I,25 (-5)	I,24 ± 0,22 (-4)
^{238}U:	Y	I0	I,82 ± 0,I0 (-6)	2,44 ± 0,06 (-5)
	$\sigma_{\gamma f}$	30	5,I2 ± I,62 (-6)	7,75 ± 0,7I (-5)
^{237}Np:	Y	I0	4,55 ± 0,30 (-6)	2,64 ± 0,09 (-5)
	$\sigma_{\gamma f}$	30	2,24 ± 0,33 (-5)	I,I9 ± 0,09 (-4)
^{239}Pu:	Y	I0	I,0I ± 0,25 (-5)	7,I5 ± I,43 (-5)
	$\sigma_{\gamma f}$	30	2,80 ± 0,7I (-5)	3,49 ± I,20 (-4)
^{241}Pu:	Y	I0	3,35 ± I,00 (-5)	2,00 ± 0,20 (-4)
	$\sigma_{\gamma f}$	30	9,I4 ± 2,90 (-5)	9,52 ± I,79 (-4)
^{241}Am:	Y	I2	I,20 ± 0,30 (-5)	I,39 ± 0,I0 (-4)
	$\sigma_{\gamma f}$	30	3,50 ± I,I2 (-5)	7,90 ± 0,73 (-4)

Continued

Isotope		Experimental error, %	E_{max}, MeV 4,7	4,8	4,9	5,0
^{232}Th:	Y	I2		2,59 ± 0,65 (-7)	I,I2 ± 0,56 (-6)	5,20 ± 0,40 (-6)
	$\sigma_{\gamma f}$	30		6,54 ± 3,37 (-7)	I,02 ± 0,20 (-6)	5,57 ± 0,88 (-5)
^{233}U:	Y	I0		I,27 ± 0,I9 (-5)	6,65 ± 0,20 (-5)	4,00 ± 0,60 (-4)
	$\sigma_{\gamma f}$	30		I,I5 ± 0,56 (-5)	7,00 ± I,90 (-4)	4,30 ± I,25 (-3)
^{235}U:	Y	I0		-	-	8,50 ± I,70 (-5)
	$\sigma_{\gamma f}$	30				I,62 ± 0,43 (-4)
^{236}U:	Y	I0		2,84 ± 0,I0 (-4)	6,32 ± 0,63 (-4)	I,25 ± 0,09 (-3)
	$\sigma_{\gamma f}$	30		I,I7 ± 0,I4 (-3)	3,5I ± 0,82 (-3)	5,56 ± I,78 (-3)
^{238}U:	Y	I0	9,27 ± 0,35 (-5)	3,20 ± 0,06 (-4)	7,27 ± 0,5I (-4)	I,65 ± 0,07 (-3)
	$\sigma_{\gamma f}$	30	9,00 ± 0,43 (-4)	2,88 ± 0,I3 (-3)	4,00 ± 0,9I (-3)	9,50 ± 2,06 (-3)
^{237}Np:	Y	I0		3,66 ± 0,2I (-4)	9,95 ± I,40 (-4)	3,II ± 0,I2 (-3)
	$\sigma_{\gamma f}$	30		I,54 ± 0,27 (-3)	7,06 ± 2,46 (-3)	2,54 ± 0,40 (-2)
^{239}Pu:	Y	I0		4,I0 ± 0,2I (-4)	3,80 ± I,06 (-4)	2,42 ± 0,I2 (-3)
	$\sigma_{\gamma f}$	30		I,45 ± 0,32 (-3)	4,60 ± I,76 (-3)	I,76 ± 0,34 (-2)
^{241}Pu:	Y	I0		8,I0 ± 0,32 (-4)	2,03 ± 0,20 (-3)	5,20 ± 0,52 (-3)
	$\sigma_{\gamma f}$	30		I,94 ± 0,42 (-3)	I,38 ± 0,29 (-2)	3,64 ± 0,86 (-2)
^{241}Am:	Y	I2		9,80 ± 0,39 (-4)	2,I8 ± 0,3I (-3)	5,67 ± 0,I7 (-3)
	$\sigma_{\gamma f}$	30		3,88 ± 0,42 (-3)	I,24 ± 0,42 (-2)	4,02 ± 0,64 (-2)

Continued

Isotope		Experimental errors, %	E_{max}, MeV 5,I	5,2	5,3	5,4
^{232}Th:	Y	I2	3,07 ± 0,22 (-5)	6,55 ± 0,38 (-5)	I,67 ± 0,07 (-4)	I,6I ± 0,05 (-3)
	$\sigma_{\gamma f}$	30	3,3I ± 0,23 (-4)	3,I0 ± 0,40 (-4)	I,06 ± 0,I3 (-3)	2,02 ± 0,I0 (-2)
^{233}U:	Y	I0	2,09 ± 0,I3 (-3)	I,26 ± 0,09 (-2)	7,55 ± 0,I5 (-2)	2,38 ± 0,04 (-I)
	$\sigma_{\gamma f}$	30	2,I2 ± 0,24 (-2)	I,4I ± 0,I5 (-I)	8,I0 ± 0,37 (-I)	I,9I ± 0,07 (0)
^{235}U:	Y	I0	2,24 ± 0,34 (-4)	8,40 ± 0,67 (-4)	3,92 ± 0,I7 (-3)	I,34 ± 0,04 (-2)
	$\sigma_{\gamma f}$	30	I,56 ± 0,63 (-3)	7,36 ± I,I9 (-3)	3,88 ± 0,28 (-2)	I,I6 ± 0,08 (-I)
^{236}U:	Y	I0	8,05 ± 0,I6 (-3)	2,70 ± 0,I9 (-2)	6,30 ± 0,I3 (-2)	I,09 ± 0,02 (-I)
	$\sigma_{\gamma f}$	30	9,27 ±0,4I (-2)	2,30 ± 0,30 (-I)	3,36 ± 0,35 (-I)	3,49 ± 0,43 (-I)
^{238}U:	Y	I0	4,62 ± 0,I5 (-3)	9,90 ± 0,50 (-3)	2,45 ± 0,07 (-2)	5,73 ± 0,I3 (-2)
	$\sigma_{\gamma f}$	30	3,44 ± 0,32 (-2)	5,25 ± 0,93 (-2)	I,56 ± 0,II (-I)	3,58 ± 0,24 (-I)
^{237}Np:	Y	I0	8,20 ± 0,24 (-3)	2,44 ± 0,I2 (-2)	7,07 ± 0,I4 (-2)	I,64 ± 0,03 (-I)
	$\sigma_{\gamma f}$	30	5,55 ± 0,46 (-2)	I,95 ± 0,I9 (-I)	5,I8 ± 0,39 (-I)	9,90 ± 0,5I (-I)
^{239}Pu:	Y	I0	6,95 ± 0,2I (-3)	I,90 ± 0,I4 (-2)	5,39 ± 0,I0 (-2)	I,36 ± 0,03 (-I)
	$\sigma_{\gamma f}$	30	5,II ± 0,45 (-2)	I,37 ± 0,I6 (-I)	3,80 ± 0,30 (-I)	9,03 ± 0,53 (-I)
^{241}Pu:	Y	I0	I,36 ± 0,04 (-2)	3,08 ± 0,26 (-2)	9,66 ± 0,I9 (-2)	I,89 ± 0,04 (-I)
	$\sigma_{\gamma f}$	30	9,42 ± 0,80 (-2)	2,68 ± 0,46 (-I)	6,66 ± 0,65 (-I)	8,65 ± 0,52 (-I)
^{241}Am:	Y	I2	I,3I ± 0,04 (-2)	2,68 ± 0,I9 (-2)	5,62 ± 0,I3 (-2)	I,II ± 0,02 (-I)
	$\sigma_{\gamma f}$	30	7,75 ± 0,9I (-2)	I,36 ± 0,2I (-I)	2,82 ± 0,43 (-I)	5,45 ± 0,45 (-I)

Continued

Isotope		Experimental error, %	E_{max}, MeV			
			5,5	5,6	5,7	5,8
^{232}Th:	Y	I2	I,02 ± 0,06 (-2)	3,45 ± 0,I0 (-2)	6,95 ± 0,35 (-2)	I,08 ± 0,04 (-I)
	$\sigma_{\gamma f}$	30	I,I3 ± 0,09 (-I)	2,72 ± 0,22 (-I)	2,66 ± 0,48 (-I)	2,44 ± 0,9I (-I)
^{233}U:	Y	I0	5,50 ± 0,I0 (-I)	I,I0 ± 0,02 (0)	I,89 ± 0,09 (0)	3,06 ± 0,06 (0)
	$\sigma_{\gamma f}$	30	2,97 ± 0,I2 (0)	4,5I ± 0,26 (0)	6,09 ± 0,6I (0)	8,I4 ± 0,86 (0)
^{235}U:	Y	I0	4,60 ± 0,I0 (-2)	I,I9 ± 0,02 (-I)	2,44 ± 0,I2 (-I)	4,70 ± 0,09 (-I)
	$\sigma_{\gamma f}$	30	3,90 ± 0,20 (-I)	7,42 ± 0,35 (-I)	I,08 ± 0,I4 (0)	2,20 ± 0,I7 (0)
^{236}U:	Y	I0	2,04 ± 0,04 (-I)	3,53 ± 0,07 (-I)	6,32 ± 0,32 (-I)	I,2I ± 0,02 (0)
	$\sigma_{\gamma f}$	30	8,20 ± I,00 (-I)	I,I3 ± 0,I9 (0)	2,38 ± 0,55 (0)	5,86 ± 0,90 (0)
^{238}U:	Y	I0	I,20 ± 0,02 (-I)	2,7I ± 0,05 (-I)	6,36 ± 0,25 (-I)	I,I9 ± 0,02 (0)
	$\sigma_{\gamma f}$	30	5,94 ± 0,40 (-I)	I,53 ± 0,09 (0)	3,84 ± 0,38 (0)	4,46 ± 0,46 (0)
^{237}Np:	Y	I0	3,94 ± 0,08 (-I)	8,90 ± 0,I6 (-I)	I,7I ± 0,09 (0)	2,99 ± 0,05 (0)
	$\sigma_{\gamma f}$	30	2,42 ± 0,I3 (0)	4,80 ± 0,2I (0)	7,I9 ± 0,98 (0)	I,05 ± 0,I0 (+I)
^{239}Pu:	Y	I0	3,46 ± 0,06 (-I)	8,02 ± 0,I5 (-I)	I,45 ± 0,07 (0)	2,44 ± 0,05 (0)
	$\sigma_{\gamma f}$	30	2,22 ± 0,09 (0)	4,35 ± 0,25 (0)	5,I5 ± 0,65 (0)	6,87 ± 0,70 (0)
^{241}Pu:	Y	I0	3,38 ± 0,06 (-I)	5,I5 ± 0,09 (-I)	7,70 ± 0,39 (-I)	I,I8 ± 0,02 (0)
	$\sigma_{\gamma f}$	30	I,04 ± 0,07 (0)	I,08 ± 0,09 (0)	I,64 ± 0,22 (0)	2,86 ± 0,39 (0)
^{241}Am:	Y	I2	2,27 ± 0,05 (-I)	4,36 ± 0,09 (-I)	7,44 ± 0,37 (-I)	I,26 ± 0,03 (0)
	$\sigma_{\gamma f}$	30	I,I4 ± 0,09 (0)	I,79 ± 0,I5 (0)	2,43 ± 0,32 (0)	4,32 ± 0,5I (0)

Continued

Isotope		Experimental error, %	E_{max}, MeV			
			5,9	6,0	6,I	6,2
^{232}Th:	Y	I2	2,I3 ± 0,06 (-I)	4,64 ± 0,I2 (-I)	I,04 ± 0,03 (0)	I,84 ± 0,09 (0)
	$\sigma_{\gamma f}$	30	9,70 ± 0,8I (-I)	2,59 ± 2,34 (0)	5,60 ± 0,49 (0)	5,50 ± 0,67 (0)
^{233}U:	Y	I0	4,68 ± 0,08 (0)	6,45 ± 0,II (0)	8,32 ± 0,I4 (0)	I,I0 ± 0,04 (+I)
	$\sigma_{\gamma f}$	30	7,78 ± 0,40 (0)	6,75 ± 0,3I (0)	6,55 ± 0,37 (0)	7,30 ± 0,33 (0)
^{235}U:	Y	I0	9,I2 ± 0,I7 (-I)	I,57 ± 0,03 (0)	2,38 ± 0,05 (0)	3,64 ± 0,I5 (0)
	$\sigma_{\gamma f}$	30	3,80 ± 0,22 (0)	4,56 ± 0,24 (0)	4,90 ± 0,5I (0)	7,02 ± 0,6I (0)
^{236}U:	Y	I0	2,28 ± 0,03 (0)	3,76 ± 0,08 (0)	5,64 ± 0,20 (0)	8,37 ± 0,84 (0)
	$\sigma_{\gamma f}$	30	9,08 ± 0,65 (0)	I,00 ± 0,I3 (+I)	I,I2 ± 0,I6 (+I)	I,35 ± 0,4I (+I)
^{238}U:	Y	I0	I,84 ± 0,03 (0)	2,62 ± 0,04 (0)	3,76 ± 0,07 (0)	5,38 ± 0,22 (0)
	$\sigma_{\gamma f}$	30	3,50 ± 0,24 (0)	4,03 ± 0,3I (0)	5,86 ± 0,48 (0)	7,I6 ± 0,74 (0)
^{237}Np:	Y	I0	4,82 ± 0,08 (0)	6,97 ± 0,I2 (0)	9,20 ± 0,32 (0)	I,20 ± 0,09 (+I)
	$\sigma_{\gamma f}$	30	I,02 ± 0,06 (+I)	9,02 ± 0,86 (0)	8,54 ± I,30 (0)	I,0I ± 0,I5 (+I)
^{239}Pu:	Y	I0	3,59 ± 0,07 (0)	4,9I ± 0,I0 (0)	6,28 ± 0,I6 (0)	8,08 ± 0,40 (0)
	$\sigma_{\gamma f}$	30	4,67 ± 0,36 (0)	3,9I ± 0,44 (0)	3,78 ± 0,45 (0)	5,03 ± 0,57 (0)
^{241}Pu:	Y	I0	I,83 ± 0,04 (0)	2,72 ± 0,06 (0)	3,85 ± 0,08 (0)	5,65 ± 0,40 (0)
	$\sigma_{\gamma f}$	30	4,I6 ± 0,32 (0)	5,23 ± 0,36 (0)	6,58 ± 0,62 (0)	I,I8 ± 0,II (+I)
^{241}Am:	Y	I2	2,04 ± 0,04 (0)	3,22 ± 0,06 (0)	4,66 ± 0,I4 (0)	6,77 ± 0,47 (0)
	$\sigma_{\gamma f}$	30	6,02 ± 0,36 (0)	7,42 ± 0,67 (0)	8,73 ± 0,95 (0)	I,23 ± 0,20 (+I)

Continued

Isotope		Experimental error, %	E_{max}, MeV			
			6,3	6,4	6,5	6,6
^{232}Th:	Y	I2	2,98 ± 0,07 (0)	4,79 ± 0,I2 (0)	7,05 ± 0,I8 (0)	9,60 ± 0,24 (0)
	$\sigma_{\gamma f}$	30	7,65 ± I,50 (0)	I,I3 ± 0,I4 (+I)	I,02 ± 0,I7 (+I)	7,95 ± I,49 (0)
^{233}U:	Y	I0	I,38 ± 0,03 (+I)	I,69 ± 0,03 (+I)	2,04 ± 0,05 (+I)	2,48 ± 0,06 (+I)
	$\sigma_{\gamma f}$	30	7,35 ± 0,64 (0)	7,67 ± 0,64 (0)	8,58 ± 0,52 (0)	I,04 ± 0,I2 (+I)
^{235}U:	Y	I0	5,25 ± 0,I3 (0)	7,00 ± 0,I3 (0)	8,98 ± 0,2I (0)	I,I3 ± 0,03 (+I)
	$\sigma_{\gamma f}$	30	7,3I ± 0,8I (0)	6,I0 ± 0,43 (0)	5,9I ± 0,68 (0)	7,20 ± 0,72 (0)
^{236}U:	Y	I0	I,I9 ± 0,04 (+I)	I,53 ± 0,03 (+I)	I,86 ± 0,06 (+I)	2,47 ± 0,06 (+I)
	$\sigma_{\gamma f}$	30	I,32 ± 0,54 (+I)	I,03 ± 0,25 (+I)	I,03 ± 0,24 (+I)	I,72 ± 0,34 (+I)
^{238}U:	Y	I0	7,I5 ± 0,I3 (0)	9,I8 ± 0,I7 (0)	I,I4 ± 0,02 (+I)	I,37 ± 0,04 (+I)
	$\sigma_{\gamma f}$	30	6,57 ± 0,93 (0)	5,80 ± 0,52 (0)	5,05 ± 0,63 (0)	4,62 ± 0,76 (0)
^{237}Np:	Y	I0	I,60 ± 0,04 (+I)	2,03 ± 0,04 (+I)	2,47 ± 0,07 (+I)	3,I2 ± 0,08 (+I)
	$\sigma_{\gamma f}$	30	I,28 ± 0,30 (+I)	I,33 ± 0,2I (+I)	I,37 ± 0,I7 (+I)	I,67 ± 0,I9 (+I)
^{239}Pu:	Y	I0	9,95 ± 0,20 (0)	I,3I ± 0,03 (+I)	I,67 ± 0,04 (+I)	2,02 ± 0,05 (+I)
	$\sigma_{\gamma f}$	30	6,95 ± I,39 (0)	I,I9 ± 0,II (+I)	I,I8 ± 0,II (+I)	9,0I ± 0,93 (0)
^{241}Pu:	Y	I0	8,I7 ± 0,I6 (0)	I,08 ± 0,02 (+I)	I,37 ± 0,04 (+I)	I,79 ± 0,05 (+I)
	$\sigma_{\gamma f}$	30	I,24 ± 0,I8 (+I)	I,II ± 0,I2 (+I)	I,I0 ± 0,II (+I)	I,29 ± 0,20 (+I)
^{241}Am:	Y	I2	9,95 ± 0,50 (0)	I,35 ± 0,07 (+I)	I,72 ± 0,09 (+I)	2,33 ± 0,I2 (+I)
	$\sigma_{\gamma f}$	30	I,64 ± 0,43 (+I)	I,54 ± 0,32 (+I)	I,5I ± 0,37 (+I)	2,0I ± 0,38 (+I)

Continued

Isotope		Experimental error, %	E_{max}, MeV			
			6,7	6,8	6,9	7,0
^{232}Th:	Y	I2	I,23 ± 0,03 (+I)	I,52 ± 0,03 (+I)	I,78 ± 0,04 (+I)	2,II ± 0,05 (+I)
	$\sigma_{\gamma f}$	30	5,45 ± I,69 (0)	3,65 ± I,I8 (0)	2,39 ± I,26 (0)	3,57 ± 5,09 (0)
^{233}U:	Y	I0	2,92 ± 0,05 (+I)	3,58 ± 0,06 (+I)	4,2I ± 0,07 (+I)	4,82 ± 0,08 (+I)
	$\sigma_{\gamma f}$	30	I,2I ± 0,I5 (+I)	I,70 ± 0,I4 (+I)	I,59 ± 0,32 (+I)	I,38 ± 0,64 (+I)
^{235}U:	Y	I0	I,46 ± 0,03 (+I)	I,78 ± 0,03 (+I)	2,I2 ± 0,04 (+I)	2,58 ± 0,05 (+I)
	$\sigma_{\gamma f}$	30	I,00 ± 0,I0 (+I)	7,80 ± I,I0 (0)	7,25 ± I,98 (0)	I,60 ± 0,80 (+I)
^{236}U:	Y	I0	3,00 ± 0,06 (+I)	3,72 ± 0,07 (+I)	4,59 ± 0,09 (+I)	5,55 ± 0,II (+I)
	$\sigma_{\gamma f}$	30	I,66 ± 0,39 (+I)	2,20 ± 0,57 (+I)	2,92 ± 0,98 (+I)	3,58 ± I,65 (+I)
^{238}U:	Y	I0	I,63 ± 0,03 (+I)	I,97 ± 0,04 (+I)	2,27 ± 0,04 (+I)	2,62 ± 0,05 (+I)
	$\sigma_{\gamma f}$	30	4,86 ± I,29 (0)	5,69 ± I,35 (0)	5,I2 ± 2,70 (0)	6,54 ± 3,40 (0)
^{237}Np:	Y	I0	3,70 ± 0,06 (+I)	4,50 ± 0,08 (+I)	5,28 ± 0,09 (+I)	6,20 ± 0,II (+I)
	$\sigma_{\gamma f}$	30	I,57 ± 0,23 (+I)	I,85 ± 0,29 (+I)	I,80 ± 0,4I (+I)	2,50 ± I,I9 (+I)
^{239}Pu:	Y	I0	2,38 ± 0,05 (+I)	2,9I ± 0,06 (+I)	3,53 ± 0,09 (+I)	4,I6 ± 0,08 (+I)
	$\sigma_{\gamma f}$	30	8,56 ± 2,3I (0)	I,43 ± 0,27 (+I)	I,92 ± 0,48 (+I)	I,75 ± 0,98 (+I)
^{241}Pu:	Y	I0	2,25 ± 0,04 (+I)	2,74 ± 0,05 (+I)	3,37 ± 0,09 (+I)	4,03 ± 0,07 (+I)
	$\sigma_{\gamma f}$	30	I,33 ± 0,2I (+I)	I,36 ± 0,27 (+I)	I,75 ± 0,54 (+I)	2,28 ± I,07 (+I)
^{241}Am:	Y	I2	2,85 ± 0,06 (+I)	3,60 ± 0,07 (+I)	4,35 ± 0,09 (+I)	5,I5 ± 0,I0 (+I)
	$\sigma_{\gamma f}$	30	I,64 ± 0,50 (+I)	I,98 ± 0,30 (+I)	I,79 ± 0,6I (+I)	I,86 ± 0,98 (+I)

NOTE. The numbers in the brackets show the powers of the quantities in the table.

APPLICABILITY OF TRADITIONAL FISSION PROBABILITY SYSTEMATICS

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(Paper submitted to Yadernaya Fizika)

A summary is given of data for the dependence of Γ_n/Γ_f on nucleonic composition.

A clear correlation is established between the structural features in the Z and N dependences of the fission thresholds, the neutron binding energy and the ratio Γ_n/Γ_f. It is shown that the shell structure of the nucleus and its rearrangement with deformation and energy play a decisive role in determining the fission probability properties of cold and heated nuclei. Arguments based on the rearrangement of nucleonic shells with change of energy throw doubt on the usefulness of systems which combine experimental data on Γ_n/Γ_f for nuclei with different degrees of excitation. From this point of view, only the limiting situations corresponding to the fission of cold and strongly heated nuclei are of interest. It is shown that the ideas on which the traditional systems are based correspond to the second asymptotic case, which is conveniently described by the drop model. The approximate range over which these ideas can be applied to the fission of cold nuclei is defined by the narrow intervals $90 \leqslant Z \leqslant 95$ and $140 \leqslant N \leqslant 146$, where the height of the maximum peak depends very little on N.

The analysis also shows that the simple description in the constant-temperature approximation, which has frequently been used with success in the past, can still be considered as a convenient tool which gives the same basic results as found by more complex methods.

PRESENT STATUS OF EXPERIMENTAL DATA ON THE VALUE OF $\alpha(^{239}Pu)$

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(Paper submitted to Yadernaya Fizika)

From an analysis of published experimental data on the ratio (α) of the radiative capture to fission cross-sections for ^{239}Pu, evaluated values (Table 1) and a covariance error matrix (Table 2) were obtained for this parameter over the neutron energy range 0.1 keV-1 MeV. The results are compared with those of other evaluations. The comparison is made in particular for α-values averaged over the core neutron spectrum of a standard Baker reactor (Table 3).

Table 1

Evaluated $\alpha(^{239}Pu)$ values in the neutron energy range 0.1 keV-1 MeV

E_n, keV	α	E_n, keV	α
0,I - 0,2	0,863	20 - 25	0,369
0,2 - 0,3	0,936	25 - 30	0,3I7
0,3 - 0,4	I,I6I	30 - 35	0,300
0,4 - 0,5	0,50I	35 - 40	0,274
0,5 - 0,6	0,736	40 - 45	0,258
0,6 - 0,7	I,497	45 - 50	0,24I
0,7 - 0,8	0,973	50 - 60	0,209
0,8 - 0,9	0,8I8	60 - 70	0,I83
0,9 - I,0	0,724	70 - 80	0,I66
I - 2	0,880	80 - 90	0,I62
2 - 3	I,020	90 - I00	0,I55
3 - 4	0,779	I00 - 200	0,I34
4 - 5	0,850	200 - 300	0,I08
5 - 6	0,825	300 - 400	0,093
6 - 7	0,787	400 - 500	0,082
7 - 8	0,624	500 - 600	0,07I
8 - 9	0,547	600 - 700	0,060
9 - I0	0,563	700 - 800	0,050
I0 - I5	0,547	800 - 900	0,040
I5 - 20	0,4I2	900 - I000	0,030

Table 2

Evaluated α-values and radiative capture cross-sections for ^{239}Pu in the format of the 26-group system of constants

Gr-oup	E_n, keV	α	Correlation matrix of errors in α													$\sigma_{n,\gamma}$, b
5	800-I400	0,029±0,008	I													0,05±0,0
6	400-800	0,068±0,0I2	0,93	I												0,II±0,0
7	200-400	0,I02±0,0I3	0,90	0,89	I											0,I5±0,0
8	I00-200	0,I34±0,0I5	0,87	0,87	0,87	I										0,20±0,0
9	46,5-I00	0,I84±0,02I	0,70	0,70	0,7I	0,7I	I									0,30±0,0
I0	2I,5-46,5	0,304±0,028	0,36	0,38	0,42	0,42	0,48	I								0,49±0,0
II	I0-2I,5	0,483±0,045	0,27	0,29	0,3I	0,29	0,33	0,36	I							0,84±0,0
I2	4,65-I0,0	0,7I4±0,064	0,28	0,30	0,32	0,30	0,32	0,36	0,45	I						I,47±0,I
I3	2,I5-4,65	0,904±0,075	0	0	0	0	0,I4	0,3I	0,49	0,46	I					2,63±0,2
I4	I,0-2,I5	0,889±0,073	0	0	0	0	0,I4	0,3I	0,49	0,46	0,87	I				3,7I±0,3
I5	0,465-I,0	0,827±0,068	0	0	0	0	0,I4	0,3I	0,49	0,46	0,87	0,87	I			6,89±0,6
I6	0,2I5-0,465	0,930±0,077	0	0	0	0	0,I4	0,3I	0,49	0,46	0,87	0,87	0,87	I		I2,0±I,0
I7	0,I00-0,2I5	0,868±0,072	0	0	0	0	0,I4	0,3I	0,49	0,46	0,87	0,87	0,87	0,87	I	I6,4±I,4

Table 3

Comparison of different $\alpha(^{239}Pu)$ evaluations averaged over the core neutron spectrum of a standard Baker reactor (without allowance for resonance self-shielding)

Ref.	⟨α⟩	Ratio to ⟨α⟩ in present paper
[I]	0,307	I,030
[2]	0,303	I,0I7
ENDF/B-III [3]	0,299	I,003
BNAB-70 [4]	0,300	I,007
ENDF/B-IV [5]	0,304	I,020
[6]	0,292	0,980
This paper	$0,298^{0,020^{x}}_{0,009^{xx}}$	I,000

x/ With allowance for the correlation matrix from Table 2.

xx/ Assuming a diagonal correlation matrix.

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CALCULATIONS OF THE (n,2n) REACTION CROSS-SECTIONS AND INELASTICALLY SCATTERED NEUTRON SPECTRA IN THE MASS-NUMBER RANGE 50-200

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(Paper submitted to Voprosy Atomnoj Nauki i Tekhniki; Seriya: Yadernye Konstanty)

Statistical theory and the pre-equilibrium decay model [1-4] are used to calculate the inelastically scattered neutron spectra and the (n,2n) reaction cross-sections for initial neutron energies of 7-15 MeV. The results for ^{52}Cr, ^{56}Fe, ^{93}Nb, ^{115}In, $^{144, 146, 148, 150}Nd$, $^{148, 150, 152, 154}Sm$, ^{181}Ta, ^{197}Au and a natural mixture of Cr, Fe and Cu isotopes are compared with experimental data. Figures 1 and 2 show the comparisons for the spectrum of 14.4 MeV neutrons inelastically scattered by tantalum and the excitation function of the (n,2n) reaction in ^{154}Sm. The error in the calculations, estimated from the uncertainty in the parameters used, is ~ 10%.

From the comparisons between the calculated and experimental data, the following conclusions are drawn:

1. For nuclei of average atomic mass, where there is strong competition between the (n,n'), (n,p) and (n,α) reaction channels, the statistical theory calculation depends more critically on the choice of level density parameters than it does with heavy nuclei. The effect of the (n,n'γ) channel competition on the value of the (n,2n) reaction cross-section is more pronounced in heavy nuclei;

2. Level density parameters with the correction δ taken as an "inverse displacement" in the excitation energy give a better overall description of the experimental data in the high excitation energy region;

3. For the majority of nuclei considered, the agreement between calculation and experiment is within 10%. The method used in the paper can therefore be applied to the prediction of neutron cross-sections and spectra in the energy and mass ranges where no experimental data are available.

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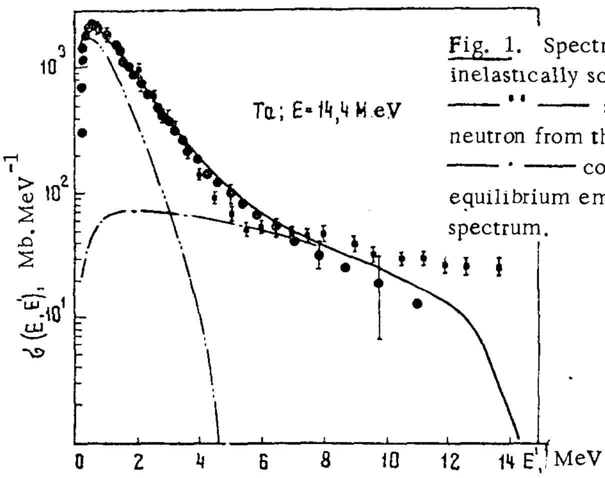
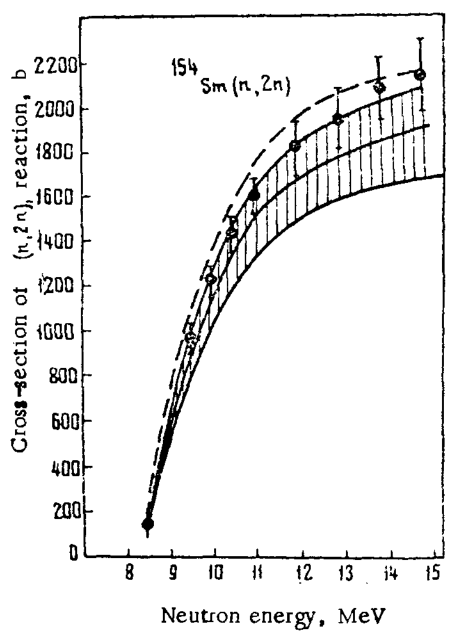


Fig. 1. Spectrum of 14.4 MeV neutrons inelastically scattered by tantalum: —— ·· —— spectrum of the second neutron from the (n,2n) reaction; —— · —— contribution from the pre-equilibrium emission; ——— total spectrum.

Fig. 2.

Excitation function of the (n,2n) reaction in the ^{142}Sm nucleus. The shaded band gives the errors in the calculated curve. The dashed line shows the calculation without allowance for the pre-equilibrium emission.



NEUTRON SPECTRA IN THE DECAY OF ISOBAR—ANALOG RESONANCES IN THE ^{109}Ag(p,n) AND ^{115}In(p,n) REACTIONS

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(Paper submitted to Yadernaya Fizika)

The neutron spectra from the decay of isobar-analog resonances (IAR) in the ^{109}Ag(p,n) and ^{115}In(p,n) reactions have been measured. The resonances E_{IAR} = 6.665 MeV and E_{IAR} = 6.965 MeV were studied for the ^{109}Ag(p,n) reactions and E_{IAR} = 6.92 MeV and E_{IAR} = 7.46 MeV for ^{115}In(p,n). For the first of these isotopes, the measurements were carried out on a time-of-flight neutron spectrometer based on the EGP-10M at the Central Institute of Nuclear Research (GDR), and for the second they were made on the fast-neutron spectrometer at the Institute of Physics and Power Engineering (USSR). In order to measure the neutron spectra at resonance and outside it, it is necessary to know the exact position of the resonance. For this purpose, the ^{109}Ag(p,n)^{109}Cd and ^{115}In(p,n)^{115}Sn excitation functions were measured for incident proton energies of 6.38–6.79 and 6.88–7.06 MeV, respectively, at intervals of 10 keV.

These studies show that the neutron spectra at resonance and outside it differ for both reactions. Since the spins of the resonances in ^{109}Ag(p,n) (1^- and 0^-) and in ^{115}In(p,n) (5^+ and 6^+) differ only by $\Delta I = 1$ and the parities are the same, the difference in the spectra cannot be explained by a statistical model. The results indicate that statistical neutron decay of IAR is not the only mechanism that exists, but that others may operate as well.

SPECTRA OF THE SECONDARY NEUTRONS EMITTED IN THE INTERACTION BETWEEN NEUTRONS AND ^{238}U NUCLEI

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(Paper submitted to Voprosy Atomnoj Nauki i Tekhniki;
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The paper presents the results of calculations made on the basis of theoretical models and semi-empirical equations of the evaporation, fission and total spectra of the secondary neutrons emitted in the bombardment of ^{238}U by 5-14 MeV neutrons.

EVALUATION OF THRESHOLD REACTION CROSS-SECTIONS AND EMITTED PARTICLE SPECTRA BY MEANS OF THEORETICAL MODELS

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(Paper submitted to Voprosy Atomnoj Nauki i Tekhniki;
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The use of theoretical models for evaluating the excitation functions of neutron-induced threshold reactions and the energy spectra of the particles emitted in these reactions is discussed.

The reactions (n,p) (n,α) and (n,2n) are considered for energies from the reaction threshold up to 20 MeV. The calculated data are compared with existing experimental results.

21-GROUP CONSTANTS FOR F, Cl, ^{232}Th AND ^{233}U

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(Paper submitted to Voprosy Atomnoj Nauki i Tekhniki; Seriya: Yadernye Konstanty)

This paper represents an extension of Ref. [1] and contains the 21-group neutron constants for F, Cl, ^{232}Th and ^{233}U. The underlying principles and the structure of the group constants remain as before.

In the resolved resonance region, the group constants have been calculated mainly from the resonance parameters by means of the MUFT program, which is a modification of MUF [2] with allowance for the Doppler effect.

In the unresolved resonance region, the group cross-sections were obtained by averaging the detailed variation.

The paper does not include a detailed analysis or consideration of the self-consistency of all the currently available experimental data on the resonance parameters and the cross-section energy dependences of the elements considered. The construction of the group constants was based mainly on evaluations already existing in the literature.

The proposed constants can be used for calculating a wide class of reactors. It should be remembered, however, that the 21-group system of constants (see Ref. [1]) is really suited only for the calculation of reactors with thermal or intermediate neutrons. Its use for calculating fast reactors may not always be valid since the system does not allow for the self-shielding effect in the typical fast-reactor energy range.

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ROLE OF COLLECTIVE EFFECTS IN THE SYSTEMATICS OF NUCLEAR LEVEL DENSITIES

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(Paper submitted to Yadernaya Fizika)

The principal relationships are given for a phenomenological description of the level density of excited nuclei which allows for pair correlations, and shell and collective effects. The systemization of experimental data on neutron resonance densities is considered. It is shown that the results of the analysis are consistent with existing theoretical and experimental information on the magnitude of the level density parameter.

PENETRABILITY OF A DOUBLE-HUMP BARRIER APPROXIMATED BY THREE CONJUGATE PARABOLAS

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(Paper submitted to Voprosy Atomnoj Nauki i Tekhniki; Seriya: Yadernye Konstanty)

The penetrability of a double-hump barrier approximated by three conjugate parabolas is found in the quasi-classical approximation by the Tsvan method. The calculations can be carried out not only for the sub-barrier case but also for the case where the incident particle energy is equal to or even greater than the barrier height. A comparison of the results with an exact numerical calculation has shown that the difference is less than 0.5% over the entire energy range. For the ^{236}U nucleus, the penetrabilities of the $(1^-, 0)$ and $(1^-, 1)$ double-hump fission barriers are calculated.

ALLOWANCE FOR THE RESOLUTION FUNCTION IN RESONANCE ANALYSIS ON THE BASIS OF THE PADE APPROXIMATION

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(Paper submitted to Voprosy Atomnoj Nauki i Tekhniki; Seriya: Yadernye Konstanty)

A method of solving the Fredholm integral equation of the first kind with a difference kernel is suggested. The method can be applied to the problem of reconstructing the energy dependence of a nuclear reaction cross-section measured with a known resolution function.

The method is based on the rational-fraction approximation of the measured and resolution functions (the kernel of the equation) with subsequent analytical Fourier transformation and inversion by means of a z-transformation. Examples of the solution of model problems by this method are given.

OPTICAL MODEL OF THE ELASTIC SCATTERING OF COMPOSITE PARTICLES

V.E. Kolesov, N.N. Titarenko

(Paper submitted to Voprosy Atomnoj Nauki i Tekhniki;
Seriya: Yadernye Konstanty)

Calculations of the elastic scattering of composite particles by atomic nuclei are made in the optical approximation. The particular form of optical program with 15 free parameters that is discussed can be used to calculate the elastic scattering of particles of arbitrary mass and with spin 0, $\frac{1}{2}$ and 1 by a spherical nucleus over a wide range of energies. The program gives the differential cross-sections for elastic scattering, the absorption cross-sections and the particle polarization: it also provides the possibility of automatic choice of model parameters on the basis of the experimental data. The results of calculations for the scattering of d, ^{4}He, ^{6}Li and ^{16}O by a number of nuclei for energies up to 90 MeV agree well with the experimental data and with test calculations made by Soviet and non-Soviet programs.

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CROSS-SECTIONS OF (n,p) REACTIONS IN THE ISOTOPES ^{58}Ni, ^{56}Fe AND ^{64}Zn FOR NEUTRON ENERGIES OF 7.6-9.3 MeV

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(Paper submitted to Voprosy Atomnoj Nauki i Tekniki;
Seriya: Yadernye Konstanty)

Measurements of (n,p) reaction excitation functions by an activation method on Ni, Fe and Zn isotopes are reported. The fast neutrons were derived from a $^{2}H(d,n)^{3}He$ reaction which was produced on the V.G. Khlopin Radium Institute cyclotron by means of standard deuterium-saturated zirconium targets on a tungsten base. The neutron energy was varied by deceleration of 6.6 MeV neutrons in tantalum foils placed in front of the target. The neutron flux was determined by means of a fission ionization chamber with a suspended layer of ^{238}U. The samples were in the shape of disks with a diameter of 7-10 mm and a thickness of 90-200 μm and were placed together with the ionization chamber at a distance of 40 mm from the centre of the neutron source. All the irradiations were carried out at an angle of 0° to the deuteron beam. The irradiation time was determined by the half-life of the radioactive reaction product and varied from 1 h for Fe to 10 h for the Ni sample. The activities were measured from the beta- and gamma-radiation yields. The beta-activity was determined in a 4πc-counter with methane through-flow. The self-absorption correction was found by taking measurements on samples of equal specific activity but different thickness and extrapolating the results to zero thickness. The gamma-activity from the irradiated samples was determined by means of a scintillation gamma-spectrometer with a 150 x 100 mm NaI(Tl) crystal. The radioactive purity of the targets was judged from a qualitative analysis of the gamma-spectra and from the absence of other activities with different half-lives. The apparatus was calibrated before and after the gamma-spectrum measurements with standard ^{65}Zn, ^{22}Na and ^{60}Co gamma-sources. A list of the errors and corrections in the cross-section determination is given in Ref. [1]. The overall standard deviation was 8–11%. The (calculated) variation in neutron energy due to slowing down of the deuterons in the zirconium layer and the effect of the experimental geometry was equal to 0.3 MeV at the half-energy points in the distribution. The results of the measurements are shown in Table 1 and Fig. 1. The figure also shows data from other work [2–6]. It can be seen that the measured cross-sections of the (n,p) reaction for the ^{56}Fe isotope agree well with the data in Ref. [4] but are slightly higher than the results of other authors [2, 3].

E_n, MeV	$\sigma_{n,p}$, mb		
	$^{56}Fe(n,p)^{56}Mn$	$^{64}Zn(n,p)^{64}Cu$	$^{58}Ni(n,p)^{58}Co$
7,6	-	249 ± 30	540 ± 40
7,7	48 ± 5	-	-
8,3	-	250 ± 30	6II ± 40
8,6	57 ± 5	-	-
8,8	-	252 ± 30	602 ± 40
9,3	66 ± 5	260 ± 30	545 ± 40

The (n,p) reaction cross-sections determined for the isotope ^{64}Zn can be compared with the only other available data in Ref. [5]. The cross-sections obtained by the present authors are smaller and good agreement is obtained only at the limits of the error ranges. The $^{58}Ni(n,p)^{58}Co$ reaction excitation function in the 7.6–9.3 MeV neutron energy range contains a maximum, which occurs at E = 8.5 MeV. The only cross-section results for this reaction in the literature (Ref. [6]) are 8% higher at the maximum: at lower energies the discrepancy is even greater.

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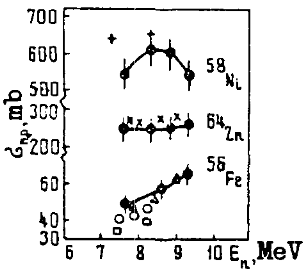

Cross-section of the (n,p) reaction in the isotopes ^{56}Fe, ^{58}Ni and ^{64}Zn: ● – present work; + – [6]; O – [3]; □ – [2]; x – [5]; △ – [4]

NEUTRON-INDUCED FISSION OF ^{227}Ac IN THE THRESHOLD REGION

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New measurements of the neutron-induced fission cross-sections of ^{227}Ac in the neutron energy range E_n = 1.6-8.6 MeV are reported. These results supplement those in Ref. [1]. For the first time, measurements have been made of the angular distributions of the neutron-induced ^{227}Ac fission fragments and the angular anisotropy of the fragments has been obtained. The most detailed results are for the fission threshold region where non-uniformities in the energy dependence of the fission probability were earlier observed in nuclei close to ^{228}Ac, namely ^{227}Ac [2], ^{228}Ra [3], and ^{227}Ra [4] nuclei.

The experiments were carried out on the low-voltage NG-400 neutron generator, a Van de Graaff electrostatic generator and the Radium Institute cyclotron. The D(d,n)^{3}He and T(p,n)^{3}He reactions were used as neutron sources. The neutrons were formed from irradiation of hydrogen-containing solid targets by deuterons or protons. It was established in control experiments that the distortion of the neutron spectra resulting from the formation of packed deuterium targets was negligibly small.

The method of measuring the actinium fission cross-sections was the same as in Ref. [1]. The neutron flux passing through the actinium was determined from the number of fission events in a natural uranium target placed up against the actinium. The method of measuring the fragment angular distributions is described in Ref. [5].

The results of the actinium fission cross-section $\sigma_{n,f}$ measurements are given in Table 1. No non-uniformities were found in the $\sigma_{n,f}$ variation near the threshold.

Table 1. Neutron-induced ^{227}Ac fission cross-sections

Neutron energy, MeV	Fission cross-section, mb	Reference	Neutron energy, MeV	Fission cross-section, mb	Reference
0,9±0,I	I,3±0,6	[I]	6,0±0,5	34±4	
I,6±0,I	2,3±0,7		6,9±0,5	37±3	[I]
I,85±0,I	4,I±0,3		7,4±0,3	46±5	
2,I±0,I	I6±2	[I]	7,9±0,4	53±5	[I]
2,3±0,05	2I±3		8,6±0,4	52±5	
2,5±0,05	25±3		9,5±0,3	60±6	[I]
2,7±0,05	3I±2		I4,0±0,I	I24±I2	[I]
2,9±0,I	33±3	[I]	I4,9±0,I	I26±I3	[I]
4,I±0,7	34±2		I6,4±0,3	I26±20	[I]
5,0±0,5	3I±3	[I]	I7,6±0,3	I5I±20	[I]
			I8,6±0,3	I40±20	[I]

The angular distributions of the actinium fission fragments can be represented by smooth curves corresponding to the relationship $W(\theta) \sim a + b \cdot \cos^2 \theta$. The least-squares method was used to determine the angular anisotropy $W(0°)/W(90°)$ (Table 2). The values are constant within the limits of error.

Table 2. Angular anisotropy of the neutron-induced ^{227}Ac fission fragments

Neutron energy, Mev	$W(0°)/W(90°)$
2,I6±0,08	I,37±0,I0
2,30±0,05	I,23±0,I5
2,70±0,08	I,4±0,I
2,9±0,I	I,4±0,I
4,50±0,I7	I,33±0,20

The actinium fission threshold, defined as the neutron energy at which the fission cross-section reaches one half of its "plateau" value, has been refined. The neutron-induced ^{227}Ac fission threshold is equal to 2.2 MeV and the fission barrier of the ^{228}Ac nucleus is correspondingly (7.2 ± 0.2) MeV.

For energies above the threshold, the ^{227}Ac fission cross-section and hence the ^{228}Ac fission probability remain almost constant, right up to the onset of emissive fission. The variation of the cross-section in this region (E_n = 3–6 MeV) can be described by a model of a nucleus with a constant temperature [6] of T = 0.4 MeV. A similar analysis of the fission probability on the first "plateau" of heavier odd–odd nuclei leads to the same value of T [7].

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INELASTIC SCATTERING OF 4.7-MeV NEUTRONS BY VANADIUM AND CHROMIUM

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Chromium and vanadium are included in the composition of the structural steels used in reactors; this means that it is necessary to know the inelastic neutron scattering cross-sections for these nuclei. In this study, the inelastically scattered neutron spectra were measured by a time-of-flight method based on pulsed operation of the EhG-5 accelerator. The neutrons were obtained from the D(d,n) reaction. The resolution at the elastic scattering peak was about 4 ns; the method used was similar to that described in Refs [1, 2]. The measurements were made at scattering angles of 20, 90 and 120°; the inelastic scattering cross-sections are the same at all three angles within the limits of experimental error and this suggests an isotropic distribution and indicates that an intermediate-nucleus mechanism plays a predominant role. The experimentally determined time-of-flight spectra for a scattering angle of 120° are shown in Fig. 1. In the case of vanadium, the peak corresponding to the inelastic scattering of neutrons by the first excited state (E_{exc} = 320 keV) is not completely resolved from the elastic scattering peak. The shape of the elastic scattering line in chromium was used to separate them. Measurements on the two samples were made under completely identical conditions. In the determination of the inelastic scattering cross-sections, the elastic interaction cross-sections were assumed to be known (and were taken from Ref. [3]). The error in the determination of the inelastic neutron scattering cross-sections is estimated by the authors as less than 10%. Table 1 shows the total cross-sections for inelastic scattering of 4.7 MeV neutrons by vanadium and chromium nuclei, corrected for multiple scattering and beam attenuation.

Table 1. Inelastic neutron scattering cross-section by vanadium and chromium, mb

Element	E_n, MeV														Elastic
	I - -I,25	I,25- -I,5	I,5- -I,75	I,75- -2	2- -2,25	2,25- -2,5	2,5- -2,75	2,75- -3	3- -3,25	3,25- -3,5	3,5- -3,75	3,75- -4	4 - -4,25	4,25- -4,5	
Chromium	49	74	50	90,4	5I,5	4I,4	I5	7,5	75,4	80,4	42,I	I0,4	0,8	0,7	2200
Vanadium	47	72	30	44	I7,6	I2,6	I0	23,4	57,8	20,I	I6	27,6	50	89	2000

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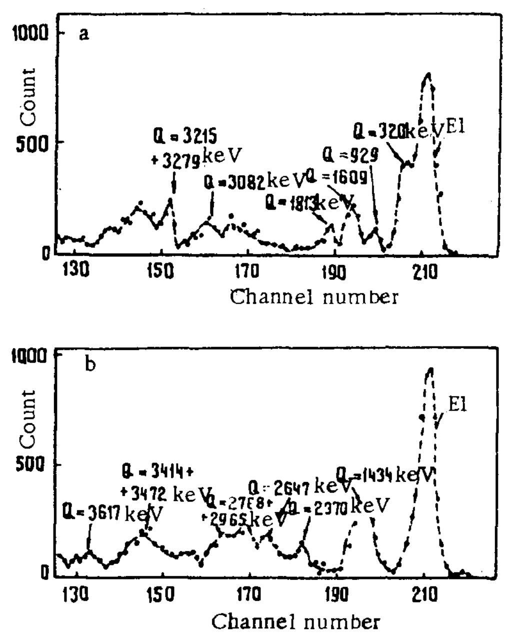
Fig. 1. Time-of-flight spectra for neutrons scattered by vanadium (a) and chromium (b)



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SCATTERING OF FAST NEUTRONS BY EVEN ISOTOPES OF ZINC

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Differential cross-sections (at angles of 20-150°) are given for elastic and inelastic neutron scattering with excitation of the first 1-3 levels of the isotopes $^{64, 66, 68}Zn$ at neutron energies of 1.5, 2.0, 2.5 and 3.0 MeV, together with a theoretical analysis in terms of the optical and statistical models.

The measurements were carried out on a 5 MV pulsed electrostatic accelerator with a fast-neutron time-of-flight spectrometer having a resolving time of 2 ns. Neutrons from the $T(p,n)^3He$ reaction with a spread of $\pm$ 50 keV were scattered by ZnO samples with a high isotopic enrichment. The experimental cross-sections were corrected for attenuation of the neutron flux in the scatterer, multiple scattering effects and the finite geometry of the experiment (anisotropy of the neutron yield from the reaction, angular resolution). The overall errors in the cross-sections include the measurement errors, the errors in the oxygen or hydrogen neutron scattering cross-sections and also the errors associated with the procedure for obtaining the cross-section values.

The experimental data are compared with theoretical calculations made in terms of an optical model having a local spherical potential and with averaged potential parameters [V_c = (48.7 - 0.33E) MeV, W_c = (7.2 + 0.66E) MeV, V_{so} = 7.5 MeV, a = 0.65Φ, b = 0.98Φ and r_o = 1.25Φ] and statistical theory with and without allowance for fluctuations in the level widths. Good agreement between the calculated cross-sections and experimental values was obtained in the case of elastic scattering. For inelastic scattering, better agreement between calculation and experiment was found with all the zinc isotopes when no allowance was made for fluctuations in the level widths. The numerical values are given in Tables 1-4.

Table 1

Differential cross-sections for elastic neutron scattering by $^{64, 66, 68}Zn$ nuclei, mb/sr

Angle, deg.	E_n, MeV			
	I,5	2,0	2,5	3,0
		^{64}Zn		
20	-	-	-	-
30	478±3I	639±28	525±33	562±39
40	369±24	435±22	309±28	308±I7
55	232±20	220±I5	II2±20	89±II
75	I2I±I9	I4I±I2	5I±I7	50±6
90	I03±I8	I24±I2	86±I6	65±7
I05	I0I±I8	I22±I2	I05±8	84±7
I25	II7±23	I06±I2	72±7	75±7
I50	I22±23	88±I2	63±6	48±6
		^{66}Zn		
20	692±38	8I2±I08	689±92	7I6±45
30	554±33	567±27	505±33	549±35
40	4I8±26	375±2I	288±28	284±I6
55	267±20	I70±I2	99±20	80±I0
75	I52±I7	II7±I2	54±I8	44±6
90	I4I±I8	I34±I2	94±I6	92±7
I05	I45±I8	I28±I2	II7±8	I08±8
I25	I33±23	II7±I2	84±7	87±7
I50	I25±23	95±I2	65±6	68±7
		^{68}Zn		
20	-	-	-	-
30	490±3I	552±26	475±32	555±27
40	348±24	368±2I	268±29	260±30
55	208±20	I76±I4	80±20	64±I0
75	I08±I7	II6±I2	62±I7	49±7
90	III±I7	III±I2	II4±I5	96±8
I05	I20±I8	I3I±I2	I36±9	III±8
I25	I39±23	II2±I2	I05±8	80±7
I50	I29±24	I26±I3	63±6	59±7

Table 2

Differential cross-sections for inelastic neutron scattering by ^{64}Zn nuclei, mb/sr

Angle, deg.	E_n, MeV						
	I,5	2,0	2,5			3,0	
	Nuclear energy level, keV						
	990 2^+	990 2^+	990 2^+	I8I0 2^+	I9I0 0^+	990 2^+	I8I0 2^+ I9I0 0^+
20	-	-	59,2±3,0	-	-	-	-
30	54,I±4,7	64,7±3,2	58,6±2,9	24,7±I,6	II,9±I,5	48,7±3,I	33,6±2,5
40	50,8±4,6	68,6±4,2	60,6±4,I	26,3±I,5	II,8±I,7	5I,I±2,8	34,0±2,4
55	53,I±5,6	67,7±3,2	60,0±2,9	24,8±I,7	II,I±I,4	47,I±2,6	33,5±2,3
75	54,9±3,8	67,9±3,0	57,5±2,8	20,8±I,5	II,2±I,4	45,7±2,6	3I,6±2,7
90	54,2±3,8	68,7±3,0	56,I±5,8	24,I±I,5	I2,I±I,4	46,5±2,7	30,9±3,0
I05	53,3±4,0	66,5±2,9	57,8±2,7	24,9±I,5	9,9±I,2	47,5±2,6	30,8±2,3
I25	52,2±3,7	65,4±3,5	59,6±3,0	23,3±I,4	8,5±I,I	46,6±2,5	34,4±2,3
I50	54,6±4,3	64,9±2,9	58,4±2,6	2I,9±2,2	I0,5±I,2	44,6±2,5	35,2±2,5

Table 3

Differential cross-sections for inelastic neutron scattering by ^{66}Zn nuclei, mb/sr

Angle, deg.	E_n, MeV					
	I,5	2,5	2,5		3,0	
	Nuclear energy level, keV					
	I039 2^+	I039 2^+	I039 2^+	I873 2^+	I039 2^+	I873 2^+
20	57,2±5,7	70,7±3,2	7I,3±2,6	32,9±2,4	59,7±4,2	32,5±3,2
30	59,0±4,3	67,6±2,7	7I,6±2,6	32,2±2,I	57,2±3,3	26,4±2,0
40	57,8±4,3	66,9±2,8	70,I±2,5	30,4±I,9	5I,8±3,I	29,I±2,0
55	60,6±4,4	66,2±2,8	69,0±2,4	30,5±I,8	52,5±2,7	28,3±I,8
75	56,7±3,9	65,9 ±2,6	67,4±2,8	29,6±2,I	50,5±3,0	25,5±I,9
90	52,6±3,7	65,4±2,4	64,2±2,2	3I,0±2,I	50,4±2,8	25,6±I,8
I05	55,6±3,7	6I,9±2,3	64,7±2,3	30,3±I,9	49,5±2,8	25,7±I,7
I25	56,9±3,6	63,0±2,3	64,9±2,3	27,6±I,6	5I,6±2,9	28,6±I,7
I50	52,2±3,6	66,4±2,7	6I,5±2,2	29,8±2,0	5I,9±3,2	27,2±I,5

Table 4

Differential cross-sections for inelastic neutron scattering by ^{68}Zn nuclei, mb/sr

Angle, deg.	E_n, MeV							
	I,5	2,0	2,5			3,0		
	Nuclear energy level, keV							
	I080 2^+	I080 2^+	I080 2^+	I650 0^+	I880 2^+	I080 2^+	I650 0^+	I880 2^+
20	-	-	-	-	-	-	-	-
30	43,8±4,8	52,6±3,5	55,3±2,5	I4,I±I,9	24,0±2,2	46,I±2,3	I4,5±I,3	2I,8±I,8
40	49,0±5,8	54,2±3,3	53,0±2,5	I3,3±I,9	2I,3±2,I	42,3±2,2	I3,5±I,5	I9,8±I,7
55	49,4±7,2	56,0±3,4	5I,I±2,8	II,2±I,8	20,2±2,2	40,3±2,I	I2,5±I,5	20,4±2,2
75	48,5±4,0	53,0±3,I	53,8±2,4	9,9±2,0	20,7±2,3	43,I±2,2	II,5±I,2	I9,6±I,7
90	49,I±4,2	5I,8±3,0	48,5±2,2	II,0±I,9	24,7±2,4	43,8±2,2	9,4±I,4	2I,0±I,9
I05	48,3±4,5	5I,5±2,8	46,4±2,I	I2,4±I,7	25,7±2,7	43,I±2,0	I0,9±I,4	22,I±2,3
I25	49,6±3,8	53,8±2,9	5I,I±2,2	I2,3±I,7	2I,5±2,4	37,5±2,0	I2,0±I,4	2I,3±I,6
I50	47,I±5,I	50,7±2,6	47,0±2,I	I5,7±I,4	23,2±2,2	36,6±2,5	I3,8±I,4	20,5±I,7