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INDC INTERNATIONAL NUCLEAR DATA COMMITTEE

USSR State Committee on the Utilization
of Atomic Energy

NUCLEAR PHYSICS RESEARCH IN THE USSR

COLLECTED ABSTRACTS

ISSUE 17

Translated by the IAEA
February 1975

IAEA NUCLEAR DATA SECTION, KÄRNTNER RING 11, A-1010 VIENNA

74-9747
Translated from Russian

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EDITORIAL BOARD

I. Institute of Physics and Power Engineering (FEI)

FRAGMENT YIELDS AND KINETIC ENERGIES IN THE SPONTANEOUS AND INDUCED FISSION OF PLUTONIUM-242

N.P. D'yachenko, V.N. Kabenin, N.P. Kolosov,
B.D. Kuz'minov, A.I. Sergachev

(Published in FEI preprint No. 366 (1973))

Fragment yields and kinetic energies were measured in the spontaneous fission of plutonium-242 and in the fission of plutonium-241 by thermal neutrons.

The kinetic energies of pair fragments were measured using semiconductor, surface-barrier, silicon detectors with a sensitive surface of diameter 2 cm. The detectors were calibrated for uranium-241 in fission by thermal neutrons.

Thermal neutrons were obtained by slowing down fast neutrons in a polyethylene block. Fast neutrons were obtained from the T(p,n) reaction. The cadmium ratio of the thermal neutron flux, as measured from ^{235}U, was ~16.

The isotopic composition of the layer used in the measurements was as follows:

Isotope	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu
Content (%)	0.3	6.4	3.7	89.5

The mean kinetic energy in spontaneous fission was 2.6 ± 0.3 MeV greater than the kinetic energy in induced fission.

Table 1

$Y\%(M)$, $E_k(M)$, $Y\%(E_k)$ for spontaneous and induced fission of ^{242}Pu

	Spontaneous fission		Induced fission	
M_n	$E_k(M_n)$, MeV	$Y\%(M_n)$	$E_k(M_n)$, MeV	$Y\%(M_n)$
162	151,53±6,17	0,012±0,012	158,43±1,2	0,052±0,006
161	153,28	0,011	159,47	0,076
160	156,04	0,023	160,80	0,108
159	157,56	0,036	161,44	0,142
158	159,29	0,052	161,96	0,206
157	160,37±2,58	0,072±0,055	162,95±0,5	0,276±0,014
156	161,48	0,118	163,88	0,357
155	162,04	0,170	164,84	0,458
154	162,27	0,211	165,93	0,598
153	163,94	0,268	166,77	0,783
152	165,79±1,77	0,355±0,063	167,43±0,25	1,006±0,026
151	167,29	0,546	168,23	1,286
150	169,08	0,830	169,27	1,611
149	169,92	1,097	170,33	1,960
148	170,73	1,318	171,38	2,356
147	172,16±0,78	1,657±0,136	172,57±0,15	2,772±0,044
146	173,66	2,167	173,71	3,282
145	174,68	2,797	174,73	3,802
144	175,42	3,193	175,70	4,312
143	176,92	3,635	176,71	4,806
142	178,03±0,55	4,230±0,217	177,86±0,12	5,250±0,061
141	178,96	4.942	178,95	5,424
140	180,50	5,556	179,90	5,870
139	181,81	5,983	180,91	6,042
138	183,46	6,886	181,87	6,214
137	184,63±0,430	7,601±0,291	182,88±0,11	6,222±0.066
136	185.22	7,701	183.78	6,013
135	185,99	7,458	184,52	5,672
134	186,71	7,181	185,14	5,232
133	187,10	6,393	185,67	4,621
132	187,01±0,50	5,275±0,243	186,04±0,15	3,864±0,052
131	186,86	4,065	186,17	2,976
130	187,08	2,953	185,96	2,164
129	187,15	1,966	185,67	1,378
128	186,95	1,116	185,30	0,860
127	185,75±1,55	0,684±0,084	184,83±0,42	0,583±0,020
126	184,97	0,437	183,49	0,382
125	185,26	0,317	182,26	0,262
124	183,13	0,236	180,83	0,186
123	178,64	0,169	178,92	0,138
122	174,71±3,84	0,128±0,038	176,60±1,25	0,106±0,009
121	175,41	0,128	174,86	0,092

Note: (1) All values given in Table 1 are corrected for neutron emission from the fragments.

(2) The errors given in Table 1 are statistica

Table 2

Spontaneous fission		Induced fission
E_k	$Y(E_k)$, %	$Y(E_k)$, %
I40	0,045 ± 0,007	0,08I ± 0,009
I42	0,092	0,II5
I44	0,086	0,I62
I46	0,093	0,249
I48	0,2I7	0,342
I50	0,362±0,020	0,523±0,024
I52	0,474	0,77I
I54	0,5I2	I,037
I56	0,785	I,4I7
I58	I,223	I,820
I60	I,660±0,043	2,355±0,05I
I62	2,I07	2,976
I64	2,803	3,575
I66	3,206	4,I67
I68	3,750	4,780
I70	4,274±0,069	5,435±0,078
I72	5,024	5,9I2
I74	5,485	6,I07
I76	5,838	6,33I
I78	6,399	6,349
I80	6,376±0,084	6,243±0,083
I82	6,I09	5,934
I84	5,880	5,569
I86	5,673	5,I67
I88	5,424	4,625
I90	5,357±0,077	3,987±0,067
I92	4,746	3,304
I94	3,746	2,792
I96	3,208	2,I92
I98	2,966	I,722
200	2,236±0,050	I,236±0,036
202	I,545	0,888
204	0,897	0,604
206	0,656	0,40I
208	0,354	0,259
2I0	0,I39±0,0I2	0,I59±0,0I3
2I2	0,088	0,09I
2I4	0,038	0,059
2I6	0,0I7	0,032
2I8	0,025	8,0I6
220	0,009±0,00I	0,007±0,00I

Note: (1) The kinetic energies given in Table 2 are not corrected for neutron emission from the fragments.

(2) The errors indicated in Table 2 are statistical.

MEASUREMENT OF THE ^{238}U TO ^{235}U FISSION CROSS-SECTION RATIO IN THE 1.4-7.4 MeV NEUTRON ENERGY RANGE

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(Paper submitted to the 2nd All-Union Conference
on Neutron Physics, Kiev 1973)

Measurements of the ^{238}U to ^{235}U fission cross-section ratio are presented for the 1.4-7.4 MeV neutron energy range. Neutrons were obtained from the T(p,n)^{3}He and D(d,n)^{3}He reactions produced on electrostatic accelerators. An ionization chamber was used as fission fragment detector. The overall accuracy of the results is about 2.5%.

Table 1

Measurements of the ^{238}U to ^{235}U fission cross-section ratio

	E_n, MeV	ΔE_n, keV	σ^8/σ^5	$\Delta\sigma^8/\sigma^5$, % *)		E_n, MeV	ΔE_n, keV	σ^8/σ^5	$\Delta\sigma^8/\sigma^5$, % *)
I	I,4	60	0,II9	2,I	22	3,6	I80	0,474	I,3
2	I,5	60	0,234	I,2	23	3,8	I60	0,476	I,4
3	I,6	60	0,300	I,0	24	4,0	I20	0,488	I,3
4	I,7	62	0,334	I,2	25	4,2	II0	0,498	I,2
5	I,8	64	0,366	I,I	26	4,4	I05	0,50I	I,I
6	I,9	66	0,397	I,0	27	4,6	I05	0,506	I,3
7	2,0	68	0,405	0,8	28	4,8	I05	0,5I2	I,2
8	2,I	70	0,4I5	I,0	29	5,0	II0	0,5I3	I,2
9	2,2	72	0,428	0,9	30	5,2	II5	0,5I8	I,2
10	2,3	73	0,430	0,8	3I	5,4	I20	0,5I8	I,2
II	2,4	74	0,432	0,9	32	5,6	I25	0,5I9	I,I
I2	2,5	75	0,432	0,8	33	5,8	I30	0,52I	I,2
I3	2,6	76	0,435	0,8	34	6,0	I35	0,527	I,3
I4	2,7	78	0,435	0,8	35	6,2	I40	0,526	I,3
I5	2,8	80	0,438	I,I	36	6,4	I45	0,538	I,I
I6	2,9	82	0,437	I,0	37	6,6	I50	0,539	I,I
I7	3,0	84	0,439	I,0	38	6,8	I60	0,546	I,I
I8	3,I	86	0,444	I,I	39	7,0	I70	0,542	I,I
I9	3,2	88	0,446	I,2	40	7,2	I80	0,532	I,0
20	3,3	90	0,452	I,3	4I	7,4	I90	0,522	I,I
2I	3,4	92	0,462	I,4					

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*/ A normalization error of 1.65% must be added to the error $\Delta\sigma^8/\sigma^5$.

RADIATIVE CAPTURE CROSS-SECTIONS FOR NEUTRONS IN THE 5-70 keV ENERGY RANGE, FOR ISOTOPES OF GADOLINIUM AND ERBIUM

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(Paper submitted to "Yadernaya Fizika")

Radiative capture cross-sections for neutrons in the 5-70 keV energy range were measured for the gadolinium isotopes ^{154}, ^{155}, ^{156}, ^{157}, ^{158}, ^{160}Gd and the erbium isotopes ^{166}, ^{167}, ^{168}, ^{170}Er. The research was performed by the time-of-flight method on a pulsed electrostatic accelerator. The time resolution was 25 nsec/m. Neutrons were obtained from the ^{7}Li(p,n) reaction. The method of measurement was based on the recording of prompt capture gamma rays by a scintillation detector having a hexafluoro-benzene volume of 17 litres. Highly enriched ($\geq$ 90%) samples of separated isotopes in the form of oxides were used. The weight of the samples was 20-50 g, and their thickness 0.005-0.01 nuclei/barn.

The capture cross-sections for the isotopes were obtained relative to the capture cross-section for indium, which served as an intermediate standard. The indium capture cross-section was measured relative to the cross-section of the ^{10}B(n,$\alpha\gamma$) reaction taken from studies by M.G. Sowerby et al. (Nuclear Data for Reactors, Proc. Symp. Helsinki (1970) 1 IAEA, Vienna (1970) 161) and R.L. Macklin, T.H. Gibbons (Phys. Rev. 165 (1968) 1147), and a gold capture cross-section at the neutron energy of 30 keV equal to 600 mb. In the determination of the capture cross-sections, corrections were made for the fact that the efficiency of recording of capture events changes from one nucleus to another; for multiple scattering of neutrons in the sample; for self-resonant self-shielding and for isotopic impurities in the sample.

The statistical errors in the results obtained for different samples were between 11 and 4% for a neutron energy of 5 keV, and less than 4% for 30 keV. The error in the cross-section of the ^{10}B(n,$\alpha\gamma$) reaction was assumed to be 2-3%, while the error in the gold capture cross-section was 4%. The systematic error due to the uncertainty in the efficiency with which the capture events are recorded and in the corrections for finite sample thickness is estimated at 6-7%. The total error in the capture cross-sections is 8-10% in the case of indium and 9-15% in that of rare-earth isotopes.

The capture cross-section values obtained are given in the Tables 1 and 2.

Table 1

Neutron radiative capture cross-sections for isotopes of Gd and Er

Nuclei mb E_n(keV)	^{154}Gd		^{155}Gd		^{156}Gd		^{157}Gd		^{158}Gd		^{160}Gd	
	$\sigma_{n\gamma}$	± Δ	$\sigma_{n\gamma}$	± Δ	$\sigma_{n\gamma}$	± Δ	$\sigma_{n\gamma}$	± Δ	$\sigma_{n\gamma}$	± Δ	$\sigma_{n\gamma}$	± Δ
5,28	29I3	484	864I	I037	I452	202	45I4	564	829	II9	602	9I
6,04	2983	44I	7924	903	I582	20I	4365	506	855	II5	523	75
6,97	25II	339	7204	77I	I38I	I67	3884	4I9	763	96	5I9	70
7,75	2003	250	6763	697	I350	I55	3809	400	640	78	422	5I
8,4	2732	347	6247	650	I2I8	I36	3528	363	663	77	40I	49
9,I3	236I	28I	5344	545	II02	I23	3038	307	672	77	363	46
9,96	2086	248	5639	553	I059	III	285I	282	575	65	366	44
I0,9	I980	236	5094	5I4	996	I00	2603	255	532	53	359	38
I2	I824	204	44I3	432	838	82	23I2	224	562	55	3II	3I
I3,3	I997	220	4778	459	I004	97	2594	249	5I0	50	347	35
I4,7	I928	224	4442	444	9I0	86	25I8	244	493	48	329	35
I6,5	I668	I92	39I9	392	803	78	2203	2II	460	45	269	27
I8,5	I485	I68	367I	37I	786	76	2030	200	446	43	289	29
20,2	I524	I78	3459	363	750	72	I933	I86	433	42	239	25
2I,3	I466	I73	333I	343	7I2	68	I855	I76	425	4I	246	24
22,4	I369	I53	3270	324	695	66	I825	I75	4I0	39	257	25
23,7	I406	I57	3I82	3I8	688	65	I843	I73	389	37	252	24
25	I387	I60	307I	304	65I	62	I729	I64	372	36	232	22
26,5	I338	I67	2954	289	620	58	I646	I55	35I	33	20I	I9
28.I	I30I	I65	2926	287	609	57	I600	I50	350	33	I95	I9
29,8	II77	I39	2767	274	590	56	I507	I42	320	30	I83	I8
3I,8	I254	I47	26I6	262	547	52	I409	I34	304	29	I67	I6
33,9	I286	I4I	254I	24I	548	52	I374	I3I	302	28	I56	I5
36,2	II83	I32	2458	234	535	5I	I352	I27	288	27	I50	I4
38,8	II27	II7	23I3	220	5I8	49	I264	II9	269	25	I52	I5
4I,7	III2	II5	2292	2I5	5I0	48	I228	II7	260	24	I53	I5
44,9	I057	III	22I0	208	480	45	II83	III	242	23	I39	I3
48,5	972	I05	2057	200	45I	43	I088	I03	238	22	I34	I3
52,5	988	I04	2008	I9I	440	4I	I045	98	230	22	I3I	I3
57	938	96	I900	I8I	4I8	39	965	9I	225	2I	I28	I2
62,2	927	97	I759	I69	389	37	854	80	2I0	20	I23	I2
68,2	903	94	I588	I5I	35I	34	720	70	I9I	I9	I07	II

Neutron capture cross-section for isotopes of E_r

Nuclei mb / E_n (keV)	^{166}Er		^{167}Er		^{168}Er		^{170}Er	
	$\sigma_{n\gamma}$	± Δ	$\sigma_{n\gamma}$	± Δ	$\sigma_{n\gamma}$	± Δ	$\sigma_{n\gamma}$	± Δ
5,23	I423	205	4I59	5I6	776	II3	43I	72
6,04	I656	232	43I9	492	657	89	392	63
6,97	II86	I39	3890	4I6	642	82	340	52
7,75	I2I2	I56	3408	358	5I2	60	34I	50
8,4	I040	II9	3I83	328	434	52	293	39
9,I3	968	I22	2842	293	429	49	259	35
9,96	I056	II2	2923	286	453	50	257	32
I0,9	987	97	258I	258	422	44	262	29
I2,0	803	79	23II	224	377	4I	249	27
I3,3	834	82	2539	246	423	44	2I5	22
I4,7	775	79	2509	256	398	4I	252	27
I6,5	770	76	2059	I93	343	36	24I	25
I8,5	76I	73	I960	I90	367	39	2I0	22
20,2	7I6	69	I826	I75	343	36	I98	20
2I,3	687	66	I784	I7I	304	35	I9I	I9
22,4	668	64	I704	I60	296	33	I88	I9
23,7	674	64	I655	I57	304	32	I92	20
25,0	637	6I	I602	I52	293	3I	I79	I8
26,5	589	55	I536	I44	280	3I	I67	I7
28,I	597	56	I496	I4I	27I	29	I58	I6
29,8	558	54	I43I	I36	258	28	I42	I5
3I,8	526	49	I385	I30	246	26	I25	I4
33,9	509	49	I346	I28	23I	26	II9	I3
36,2	493	47	I290	I23	23I	25	I2I	I3
38,8	458	44	I24I	II7	2I3	22	II9	I2
4I,7	459	44	I227	II7	204	23	I22	I3
44,9	428	4I	II39	I07	I93	20	II5	I2
48,5	402	38	I083	I03	I92	2I	I08	II
52,5	388	37	I06I	I0I	I92	20	I04	II
57	374	35	I005	95	I8I	I8	I09	II
62,2	348	33	98I	93	I8I	I8	98	II
68,2	320	3I	943	90	I75	I8	9I	I0

Table 2

Neutron radiative capture cross-sections for indium and gold

Element mb / E_n (keV)	Au		In		Element mb / E_n (keV)	Au		In	
	$\sigma_{n\gamma}$	±Δ	$\sigma_{n\gamma}$	±Δ		$\sigma_{n\gamma}$	±Δ	$\sigma_{n\gamma}$	±Δ
5-6	2I66	II7	I688	I65	32-34	555	25	8I6	65
6-7	I882	I0I	I465	I36	34-36	553	25	797	64
7-8	I66I	87	I487	I32	36-38	543	25	754	60
8-9	I506	79	I375	I22	38-40	523	25	7I7	57
9-I0	I347	65	I444	I26	40-43	482	23	693	55
I0-I2	I202	58	I294	I06	43-46	449	22	652	52
I2-I4	993	48	II93	97	46-49	436	2I	623	49
I4-I6	882	42	I075	89	49-52	423	20	606	48
I6-I8	846	4I	I098	9I	52-56	405	I9	586	46
I8-20	745	36	I040	85	56-60	387	I9	557	44
20-22	675	32	994	80	60-64	377	I8	539	43
22-24	660	32	976	78	64-68	37I	I8	52I	42
24-26	652	30	9I8	74	68-72	363	I7	499	40
26-28	630	27	888	7I	72-76	354	I7	480	38
28-30	6II	24	864	69	76-80	342	I6	47I	38
30-32	566	25	836	67	80-84	324	I6	443	36

MEASUREMENT OF NEUTRON CROSS-SECTIONS BY THE SCANNING METHOD

Yu.Ya. Stavisskij

(Paper submitted to the 2nd All-Union Conference on Neutron Physics)

Neutron energy scanning involving the use of direct-acting accelerators and threshold (p,n) reactions as well as total neutron cross-sections and their resonance structure served as the basis for a detailed study of the energy dependence of neutron cross-sections with a known energy resolution and with direct calibration of the energy scale. Consideration is given to the special problems associated with application of the method to fission and radiative capture cross-section measurements, to determination of the number of secondary neutrons in fission and to measurements of other neutron-induced processes.

THE NEUTRON SPECTRUM IN A HOMOGENEOUS MEDIUM OF ^{238}U:H

A.P. Platonov, A.A. Luk'yanov

(Article submitted to "Nuclear Constants")

A description of the method used to calculate the neutron collision density in a homogeneous infinite medium containing nuclei of ^{238}U and H in the 1-500 eV energy range is given together with the results obtained. It is shown that the collision density in the region of the individual scattering resonances differs greatly from the asymptotic value normally employed in the calculation of resonance integrals and group characteristics.

THE USE OF THEORETICAL MODELS IN EAVLUATING NUCLEAR DATA

V.M. Bychkov, V.V. Vozyakov, A.G. Dovbenko,
A.V. Ignatyuk, V.P. Lunev, V.G. Pronyaev,
V.S. Shorin

(Paper submitted to the 2nd All-Union Conference on Neutron Physics)

Optical and statistical models of the nucleus are now widely used in analysing the experimental fast-neutron cross-sections. There are various modifications of these models depending on how the contributions of the direct processes are taken into account and what assumptions are made regarding the density of the states of the excited nucleus. With the ^{56}Fe nucleus serving as an example, the use of these models is considered for the evaluation of neutron cross-sections. The theoretical relationships provide a basis for more rigorous interpolation and, what is particularly important, extrapolation of the curves of the different cross-sections; they are also an indispensable means of confirming the reliability and consistency of an evaluation.

SEPARATING THE CONTRIBUTIONS MADE BY DIRECT AND COMPOUND MECHANISMS OF REACTIONS IN RADIATIVE CAPTURE CROSS-SECTIONS

A.G. Dovbenko, A.V. Ignatyuk, V.A. Tolstikov

(Paper submitted to the 2nd All-Union Conference on Neutron Physics)

The results of a theoretical study of the energy dependence of the radiative capture cross-section for fast neutrons are considered. In the determination of the contribution of the various mechanisms, special importance attaches to those nuclei for which the measured cross-sections in the 4-7 MeV neutron energy range fall below the capture cross-section of 14 MeV neutrons. For these nuclei (Rb, Ba) the 14 MeV neutron capture cross-section can be adequately described in terms of a collective capture model, while the lower part of the cross-section can be used to check the energy dependence of the level density and of the radiation strength function.

THE MECHANISM OF DIRECT INELASTIC NEUTRON SCATTERING

A.A. Luk'yanov, E.N. Saprykin

(Paper submitted to the 2nd All-Union Conference on Neutron Physics)

In studies on the spectra of inelastic neutron scattering for bombarding particles of relatively high energy ($\gtrsim$ 9-14 MeV), deviations of the hard part of the observed spectra from the Maxwellian and asymmetries of the angular distributions can be qualitatively explained by the mechanism of direct knocking-out of nucleons from the target nucleus.

The reaction amplitude in this process, which is very easily obtained from the formalism of the nuclear-reactions dispersion theory, has no energy peculiarities and depends on the magnitude of the imparted pulse $q = |\vec{k}_1 - \vec{k}_2|$, where $\vec{k}_1$ and $\vec{k}_2$ are the momenta of the incident and inelastically scattered neutrons.

A contribution to the reaction amplitude is also made by direct inelastic transitions of a collective type and by compound nucleus states of different complexities (including single-particle states).

The general form of the amplitude of the inelastic-scattering reaction is given together with approximate forms for various specific applications. Calculations and comparisons with experimental data are presented.

THE CONTRIBUTION OF DIFFERENT PROCESSES TO THE FAST NEUTRON INTERACTION CROSS-SECTION

V.M. Bychkov, A.V. Ignatyuk,
V.T. Lunev, V.G. Pronyaev,
V.S. Shorin

The authors consider the contributions of various nuclear reaction mechanisms to the cross-section for interaction of 7-14 MeV neutrons with the ^{56}Fe nucleus. The angular distributions of elastically-scattered neutrons are analysed by the connected-channels method. The optical-potential parameters obtained are used to separate out the contribution of direct processes to the excitation functions for low-lying collective states of the nucleus.

The excitation functions and the hard part of the evaporative spectrum are affected not only by direct processes but also to a considerable extent by neutrons emitted during the stage preceding the formation of the thermodynamically equilibrated compound nucleus. They are described in terms of a model of pre-equilibrium disintegration with the characteristics of particle-hole states calculated from the superfluid nucleus model. If pair correlations are taken into account, the spectra of these neutrons and their contribution to the neutron elastic scattering cross-section differ greatly from the results obtained with the simple model of non-interacting particles.

THE LEVEL DENSITY OF LIGHT NUCLEI

A.V. Ignatyuk, Yu.V. Sokolov,
Yu.N. Shubin

(Paper submitted to the 2nd All-Union Conference on Neutron Physics)

For a number of light nuclei ($A \approx 70$) experimental data now exist on the density of excited states in the 0-20 MeV energy range. The energy dependence of the level density observed in this wide range cannot be described by means of the conventional Fermi-gas model, and the data are therefore often interpreted by having recourse to phenomenological correlations based on modifications of the Fermi gas model with an appropriately selected effective excitation energy. The physical meaning of these correlations is generally unclear, and the modifications themselves need to be justified.

This paper studies the possibilities offered by all the existing data based on the superfluid nucleus model. The distribution of levels near the ground state is discussed in detail. The calculated results adequately reproduce the observed energy dependence of the level density and they help to understand the meaning of various modifications used in cruder models. The authors examine the dependence of the calculated results on the single-particle level scheme and on the residual interaction parameters.

EVEN-ODD EFFECTS IN THE DENSITY OF NUCLEAR LEVELS

A.V. Ignatyuk, Yu.V. Sokolov

(Paper submitted to the 2nd All-Union Conference on Neutron Physics)

The superfluid-model description of particle-hole excitations is used as a basis for analysing the nature of even-odd differences in nuclear level density. The ^{56}Fe and ^{55,56}Mn nuclei satisfactorily describe the experimental data in the wide range of excitation energies from 0-20 MeV.

II. I.V. Kurchatov Atomic Energy Institute

NUCLEAR DATA FOR THERMONUCLEAR REACTORS

O.V. Bochkarev, E.A. Kuz'min,
N.I. Sidorov, L.V. Chulkov,
G.B. Yan'kov

(Paper submitted to the 2nd All-Union Conference on Neutron Physics)

The paper discusses the nuclear data needed for constructing a thermonuclear reactor working on the D-T cycle.

An analysis is made of experimental and evaluated nuclear data published before 1973 for isotopes of lithium and structural materials such as niobium and vanadium, and also for various other materials which it is now proposed to use in the blanket of a thermonuclear reactor. The nuclear data requirements for these reactors are discussed in the concluding part of the paper.

EFFECT OF THE SHELL STRUCTURE OF A NUCLEUS ON NEUTRON STRENGTH FUNCTIONS

Yu.V. Adamchuk, D.F. Zaretskij,
V.K. Sirotkin, M.G. Urin,
Yu.G. Shchepkin

(Paper submitted to the 2nd All-Union Conference on Neutron Physics)

It is well known that the simple optical model encounters considerable difficulties in describing how the strength functions vary with atomic weight [1]. In this paper the neutron strength functions are considered on the basis of the shell model approach to the theory of nuclear reactions [2, 3], account being taken of the Pauli principle. The main differences between this approach and the optical model are in the region of nuclei where a single-particle level with a given spin and parity is on the Fermi surface. For s-neutrons, this means nuclei with A~120, i.e. in the range in which the greatest discrepancy exists between optics and experiment [4]. The model so developed could be used for calculating neutron s- and p-strength functions; for spherical nuclei these calculations were in satisfactory agreement with experiment. In particular, it was possible to determine the position and magnitude of the minima of s- and p-strength functions. The number of parameters was the same as in the simple optical model.

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NEUTRON-RESONANCE PARAMETERS FOR TECHNETIUM-99

Yu.V. Adamchuk, Yu.G. Shchepkin, G.E. Muradyan,
M.A. Voskanyan

(Paper submitted to the 2nd All-Union Conference on Neutron Physics)

The paper presents measurements of total neutron cross-sections, radiative capture cross-sections and self-indication of the radioactive fission-fragment element technetium-99. Nuclear-physics data on technetium in a wide range of neutron energies are extremely important in many different branches of physics and technology, from reactor construction and nuclear physics to astronomy (in connection with the problem of the origin of the elements).

The measurements were made by the time-of-flight method on the Institute's linear electron accelerator with a resolution of 12 nsec/m. Use was made of three metallic samples of Tc of high purity and enrichment (99.99%) with a total weight of 100 grams.

Resonance-level parameters were obtained in the 0.02-2 keV energy range and strength-function values were also obtained. The statistical properties of the neutron-resonance parameters were studied.

In the 5-200 eV range twice as many levels were observed as in the previously available data, and the parameters of known resonances were corrected; information was obtained for the first time in the range above 200 eV.

MEASUREMENT OF THE ALPHA COEFFICIENT FOR PLUTONIUM-239 IN THE 3-100 keV NEUTRON ENERGY RANGE

P.E. Vorotnikov, V.A. Bukolov,
E.A. Koltypin, Yu.D. Molchanov,
G.B. Yan'kov

(Paper submitted to the 2nd All-Union Conference on Neutron Physics)

The paper describes the experimental methodology applied and the results obtained in measuring the ratio between the neutron radiative capture cross-section and the fission cross-section for plutonium-239 in the 3-100 keV energy range. Neutrons were obtained from the $^7Li(p,n)^7Be$ reaction. The electrostatic accelerator was operated in the pulsed regime. The measurements were made at an angle 0° to the proton beam; the energy of the primary neutrons was determined by the time-of-flight method with a time resolution of 8 nsec. The relative yields of gamma rays and fission neutrons were used to determine the energy dependence of alpha. Fast neutrons and gamma rays were detected using stilbene crystals and were separated from each other by an n-γ identification circuit. For determination of the absolute values of alpha, the main measurements were accompanied by the detection of fission fragments in a scintillation chamber and in addition use was made of the value of alpha given in the literature for 30 keV.

The paper includes an analysis of the possible measuring errors. The data obtained are compared with the results of other authors.

NEUTRON YIELD IN THE INTERACTION OF PROTONS WITH TRITIUM

E.A. Kuz'min, N.I. Sidorov, A.R. Fajziev,
L.V. Chulkov, G.B. Yan'kov

The paper presents differential cross-section measurements for the $T(p,n)^3He$ reaction in the 6.5-15.3 MeV proton energy range, together with the neutron cross-sections and energy spectrum for tritium break-up in the case of proton energies of 11.2-15.3 MeV at an angle of 0°.

The interactions of neutrons with energies higher than 7-8 MeV are of particular interest, especially in connection with research on controlled thermonuclear fusion. The work reported is a study of the possibilities of using neutrons produced in the reactions between protons and tritium in the energy range of 8-15 MeV.

Protons were accelerated in the cyclotron at the Atomic Energy Institute and used to bombard a solid target containing tritium absorbed in a layer of Ti (thickness 8 mg/cm^2) on a ^{58}Ni backing. The measurements were based on the time-of-flight method. Neutrons were detected by a 5 x 5 cm stilbene crystal, placed at a distance of 6 m from the source. A n-γ identification circuit was used for reducing the background. The neutron detection threshold was 1.5 MeV. The efficiency of the counter was determined by the Monte Carlo method.

The relative yield of neutrons was measured at an angle of 0°. There was practically no background in the region of the mono-energetic group from the $T(p,n)^3He$ reaction. The error in the relative measurements was not more than 6%. Absolute values of the cross-sections were determined by normalizing the points in accordance with the weighted-average data given by Wilson et al. [1]. The cross-sections obtained are given in Table 1 and in Fig. 1, which also shows the curve Wilson et al [1]. At proton energies above 8.34 MeV the tritium break-up reaction becomes possible, so that a continuous spectrum of neutrons appears. The neutron continuum was measured at 0° for proton energies of 11.2, 14.2, and 15.3 MeV. The neutron yield was determined by channel-wise subtraction of the data obtained with a tritiated target and with an identical target without tritium.

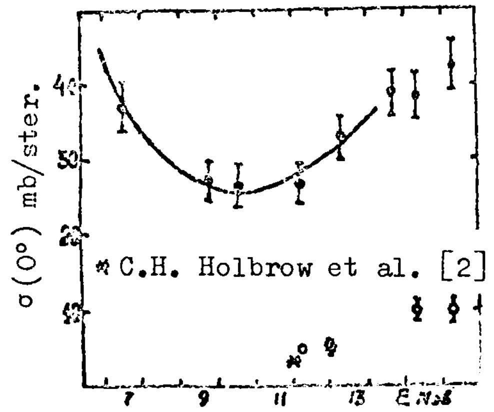
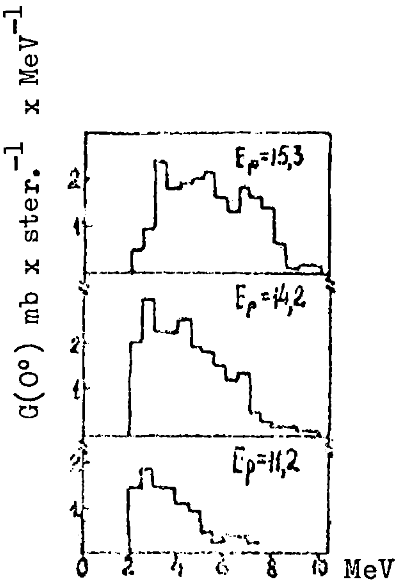


Fig. 1. Differential cross-sections for $T(p,n)^3He$ and the tritium break-up reaction at an angle of 0° as functions of proton energy in the laboratory frame of reference.



<u>Fig. 2</u>. Energy spectrum of neutrons from the tritium break-up reaction at proton energies of 11.2, 14.2 and 15.3 MeV in the laboratory frame of reference.

Table 1

E_p (MeV)	6.5	8.8	9.6	11.2	12.3	13.7	14.2	15.3
$\sigma(0°)$	37.2	24.4	26.4	26.8	32.8	38.9	38.5	42.6
mb/ster.	±3.4	±2.5	±2.4	±2.5	±3.0	±3.6	±3.5	±3.9

The background was about 90%. The error in the various points of the neutron spectral yield is estimated from the scatter in the different series and does not exceed 20%. The energy spectra of neutrons averaged over a range of 0.5 MeV are shown in Fig. 2. The effective cross-sections for the break-up neutron yield at $E_n > 2$ MeV were determined with reference to the yield of the mono-energetic group. The cross-sections obtained are given in Fig. 1. At $E_p = 11.2$ MeV the upper limit of the cross-section was estimated to be 4.6 mb/ster., and at $E_p = 14.2$ and 15.3 MeV the cross-sections were 10.5 ± 1.6 mb/ster. and 10.1 ± 1.4 mb/ster., respectively. For comparison, the data from Holbrow et al.[2] are also given in Fig. 1. Thus, at proton energies higher than 11 MeV the beam of neutrons contains continuum neutrons (about 20%) along with the mono-energetic lines.

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III. Joint Institute of Nuclear Research

THE STRUCTURE OF NEUTRON RESONANCES

V.G. Solov'ev

(Paper submitted to the 2nd All-Union Conference on Neutron Physics)

Study of the structure of neutron resonances is approached in a new way: first, by general semi-microscopic description based on the operator form of the wave function and, second, by numerical calculations based on a model which takes account of the interaction of quasi-particles with phonons.

The wave function of a highly excited state of an atomic nucleus is presented in the form of a quasi-particle number expansion. Neutron, radiation and alpha widths are expressed by coefficients of this wave function. From experimental data on reduced neutron and radiation widths one can obtain single-quasi-particle and two-quasi-particle components of the wave functions of neutron resonances equal to 10^{-6} and 10^{-9}, respectively. Two hypotheses are discussed in regard to multiple-quasi-particle components of the wave functions of neutron resonances: first, there is a large number of components and they are all small; second, a few of the many components are large ones. The magnetic moments of the neutron resonances are calculated and it is shown that they must be close to the single-particle value.

The level densities calculated in this model with I^{π} at neutron binding energies agree with the experimental values to within a factor of two. The fragmentation of single-particle states is calculated for many nuclear levels. The calculated strength functions for s and p neutrons agree with the experimental data to within an order of magnitude. The model wave functions of neutron resonances contain large multiple-quasi-particle components.

USE OF THE $^{143}Nd(n,\gamma\alpha)^{140}Ce$ REACTION TO ANALYSE THE CHARACTERISTICS OF GAMMA TRANSITIONS NEAR THE NEUTRON BINDING ENERGY

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V.I. Salatskij, V.G. Tishin, V.I. Furman

(Paper submitted to the 2nd All-Union Conference on Neutron Physics)

The authors present the results of a study of a two-stage decay process of a neutron resonance with spin 4^- (ejection of a soft quantum followed by the emission of an alpha particle). Examination of these results in conjunction with data on the analogous decay of the compound 3^- state in the ^{144}Nb nucleus has made it possible, for the first time, to obtain information regarding γ transitions between the compound states of nuclei. The main contribution is apparently made by type M1 transitions and, to a smaller extent, E1 transitions. Forbiddenness factors were obtained for gamma transitions between states near the neutron binding energy with respect to Weisskopf's single-particle evaluation. On average, they were greater (by 2 or 3 orders of magnitude) than for gamma transitions between more simple weakly excited states (in the case of E1 transitions).

In addition, values were obtained for the total alpha widths (or their upper value) for 16 resonances.

NEW DATA ON THE α-DECAY OF NEUTRON RESONANCES

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Kim Tkhe Seb, Yu.P. Popov,
V. Semenov

(Paper submitted to the 2nd All-Union Conference on Neutron Physics)

Total α-widths of neutron resonances are presented for ^{147}Sm, ^{151}Eu, ^{155}Gd, ^{177}Hf nuclei, together with preliminary information on ^{105}Pd. The measurements were performed by the time-of-flight method with a multi-section proportional chamber on the neutron beam from a pulsed reactor at the Joint Institute of Nuclear Research.

In the case of ^{147}Sm the total α-widths were studied for 50 resonances. Attention is drawn to the non-static behaviour of the dependence of the incremental sum Γ_α on the neutron energy; this behaviour is not related to any grouping of resonances with a particular spin. The observed enhancement of α-transitions to the single-phonon 2^+ state is in qualitative agreement with the theoretical assumption of the semi-microscopic approach.

New physical information was obtained from a study of the α-decay of highly excited states of deformed nuclei of ^{151}Eu, ^{155}Gd and ^{177}Hf.

The slight changes in the total alpha width from one level to another point to the possible occurrence of an α-decay process involving a few of the output channels.

Comparison of the experimental total α-width data for deformed nuclei with those for spherical nuclei shows that they are described with the same accuracy in the optical model. This gives reason to assume that the effects of a change in the deformation and pair correlations did not contribute significantly to the probability of α-decay in highly excited states of deformed nuclei.

ALPHA DECAY OF NEUTRON RESONANCES IN THE $^{149}Sm(n,\alpha)^{146}Nd$ REACTION

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R.F. Rumi, V.I. Salatskij

(Paper submitted to the 2nd All-Union Conference on Neutron Physics)

In many of the studies on the $^{149}Sm(n,\alpha)^{146}Nd$ reaction carried out on thermal neutrons it is difficult to interpret the results reliably in terms of partial α-widths, since the thermal cross-section is determined both by the resonance $E_0 = 0.098$ eV and by a negative level. In our work we studied this reaction on resonance neutrons, using the IBR-30 reactor and the time-of-flight method. Amplitude spectra of α-particles were measured in the 0.025-1.0 eV neutron energy range. By analysing the results we were able to separate out the partial α-widths of resonance $E_0 = 0.098$ eV with spin 4^- and of the bound level with spin 3^-. The energy of the bound level was approximately 0.5 eV. Partial α-widths of a number of higher resonances were also evaluated.

THE PROPERTIES OF PARTIAL RADIATION WIDTHS IN THE ^{147}Sm(n,γ)^{148}Sm REACTION ON RESONANCE NEUTRONS

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(Paper submitted to the 2nd All-Union Conference on Neutron Physics)

Using the IBR-30 pulsed fast reactor in conjunction with a linear electron accelerator, the authors applied the time-of-flight method to obtain spectra of the hard gamma rays accompanying neutron decay in 24 resonances of a ^{147}Sm target.

An analysis of these spectra led to new conclusions regarding the spins of the resonances and the spins and parities of finite states of the ^{148}Sm nucleus. A direct population of 33 states of the ^{148}Sm nucleus with positive parity lying below 2.9 MeV was observed. Important new information was obtained regarding 23 of these states. The intensities obtained for the primary transitions were used to analyse their fluctuations. It was shown that there is no contradiction with the so-called statistical distribution of Porter and Thomas. A study was made of the correlations existing between the partial radiation widths and the neutron widths of the resonances and those between the various partial widths. All experimental values of the correlations for different sets of finite states conform to the assumption of the statistical model regarding non-correlated widths. Correlations between partial α-widths and partial radiation widths are discussed.

AN ANALYSIS OF SECONDARY GAMMA QUANTA EMITTED AFTER THE CAPTURE OF RESONANCE NEUTRONS BY ^{147}Sm NUCLEI

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S. Pospishil, S.A. Telezhnikov, V.G. Tishin

(Paper submitted to the 2nd All-Union Conference on Neutron Physics)

The IBR-30 pulsed fast reactor was used in conjunction with the linear accelerator at the Laboratory of Neutron Physics to obtain the spectra of soft gamma rays emitted after the capture of resonance neutrons by ^{147}Sm nuclei. By analysing these spectra for a given set of neutron energies, the authors obtained relative populations of levels of the ^{148}Sm nucleus for individual neutron resonances with excitations of 550, 1162, and 1180 keV with corresponding spins and parities 2^+, 3^- and 4^+. For a given resonance spin, fluctuations were observed in the relative populations. These fluctuations are compared with the values predicted by the statistical model for the case of different assumptions regarding the photon strength function.

NEUTRON RESONANCE SPINS IN $^{111,\ 113}$Gd, ^{157}Gd, $^{161,\ 163}$Dy

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(Paper submitted to the 2nd All-Union Conference on Neutron Physics)

A detector comprising 4 NaI crystals was used on the neutron spectrometer in the Laboratory of Neutron Physics, Joint Institute of Nuclear Research, to continue studies of neutron resonance spins in respect of gamma quanta multiplicity [1]. Since the methods employed are not universally applicable, we tried - by calculation and by experiment - to find isotopes (for samples) in which a reliable division of s-resonances into two groups with different spins could be observed. The possibility of determining the resonance spins was checked experimentally on samples of ^{171}Yb, natural Sb ($^{121,\ 123}$Sb), natural Cd ($^{111,\ 113}$Cd), ^{157}Gd, natural Dy ($^{161,\ 163}$Dy).

For ^{171}Yb, $^{121,\ 123}$Sb, no spin effects could be found. With the remaining isotopes a pronounced splitting of the resonances into two groups can be observed, so that spin identification of the resonances is possible for these isotopes.

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STUDY OF THE SPONTANEOUSLY FISSIONING ISOMER $^{234}_{92}U$ IN THE $^{235}_{92}U(n,\gamma)$ REACTION

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(Paper submitted to the 2nd All-Union Conference on Neutron Physics)

Data on the energy of spontaneously fissioning isomers, and also on the pattern of their formation in different nuclear reactions [1], lead to the assumption that shape isomers are involved. Strutinsky's model, taking into account the influence of shell effects on the fission barrier [2], provides a good basis for expanding the nature of spontaneously fissioning isomers. However, there is as yet no direct evidence that fissioning isomers are strongly deformed. It is therefore very important to obtain information on electromagnetic transitions leading to the formation of isomers, especially in the (n,γ) reaction.

In the present work we tried to observe the formation of the spontaneously fissioning isomer $^{236m}_{92}U$ ($T_{\frac{1}{2}}$ = 130 nsec) in the $^{235}_{92}U(n,\gamma)$ reaction, and also the accompanying gamma radiation. Neutrons of ~60 keV energy were obtained in the T(p,n) reaction on the electrostatic generator in the Laboratory of Neutron Physics. Fission events were detected from prompt fission neutrons by means of a stilbene crystal and an n-γ separating circuit based on pulse shape [3]. Gamma quanta of energy higher than 0.2 MeV were also recorded with a stilbene crystal or by a liquid scintillator. The pulses from the neutron detectors and gamma-ray detectors were passed to a time-amplitude convertor, so that the prompt fission peak and the delayed "γ-n" coincidences could be observed. The results obtained in the experiments show that the yield of the isomer $^{236m}_{92}U$ in the (n,γ) reaction normalized for the prompt fission cross-section σ_i/σ_f is not more than 1.5×10^{-4}. This value is not in contradiction with the data given by Popeko et al. [4], where the yield of X-rays in thermal neutron capture was measured.

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IV. Institute of Theoretical and Experimental Physics

MEASURING THE AVERAGE NUMBER OF SECONDARY NEUTRONS FOR PLUTONIUM-239 IN THE 0.01 TO 40 eV ENERGY RANGE

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S.I. Sukhoruchkin

(Paper submitted to the 2nd All-Union Conference on Neutron Physics)

The measurements were performed because it is necessary to take into account the possible spin dependence of the average number of secondary neutrons per fission event in the different methods of measuring the alpha constant. The ratio between the count of coincidences from fast fission neutrons to the total count was determined. Using the thermal range for normalization, the authors obtained the relative dependence of $\bar{\nu}$ on the neutron energy in the 0.01-40 eV energy range.

It can be concluded from the data obtained in our work that the value of $\bar{\nu}$, measured by threshold detectors with a mean accuracy of 1%, for the thermal range and for resonances of energy up to 40 eV, can be regarded as constant and that the possible systematic error in alpha arising in resonance normalization is small (for an accuracy of 5-10% in alpha).

V. V.G. Khlopin Radium Institute

MEASUREMENT OF THE ^{235}U FISSION CROSS-SECTIONS FOR 2.5 MeV NEUTRONS

I.M. Kuks, L.A. Razumovskij, Yu.A. Selitskij,
A.V. Fomichev, V.B. Funshtejn, V.I. Shpakov

The fission cross-section of ^{235}U was measured for 2.5 MeV neutrons, the neutron flux being determined from the associated charged particles. The methods employed and the experimental conditions correspond exactly to those described and used in an earlier study [1], on measurement of the ^{238}U fission cross-section. Neutrons were obtained from the D(d,n)^{3}He reaction. The ^{3}He nuclei accompanying the neutrons were detected by low-pressure gaseous proportional counters. Fission fragments were detected by thin mica sheets [2]. A stack of 10 layers of uranium and 5 layers of mica was arranged in such a manner that each mica sheet detected fragments from the layers of uranium pressing against it on both sides. The targets, prepared by vacuum evaporation of uranium fluoride on polished aluminium foils of 0.1 mm thickness, had a diameter of 19 mm. The total weight of ^{235}U was 5.32 ± 0.07 mg. The weight was determined from the α-count of the targets, the specific activity of the uranium used, and its isotopic composition (^{235}U-89%, ^{238}U-10%, ^{234}U-1%). Within the limits of error the same weight value was obtained by separating the α-particles of ^{235}U and its half-life from the full spectrum [3]. In calculating the fission cross-sections, account was taken of the corrections described by Kuks et al. [1].

Finally, a fission cross-section of 1.30 ± 0.05 barn was obtained. The most recent recommended value in the literature is 1.29 ± 0.03 [4].

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DETERMINING THE MEAN NUMBER OF NEUTRONS PER FISSION EVENT FOR ^{252}Cf

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O.A. Migun'kov, G.M. Stukov,
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I.A. Yarytsina

(Paper submitted to the 2nd All-Union Conference on Neutron Physics)

For the measurements of $\bar{\nu}$ (^{252}Cf) the authors made separate determinations of the neutron yield of the target and the rate of fissions in it. The target was prepared from purified californium by thermal diffusion onto a thin (0.3 mm) backing of stainless steel. The ^{252}Cf content in the target layer (estimated from the α-activity) was 95.6% at the time of purification.

The neutron yield of the target was determined by three independent methods:

(a) In a graphite sphere with successive calibration by the associated particles, using the $T(d,n)^4He$ reaction;

(b) By gold activation in a water tank;

(c) By the manganese bath method.

Using all three of these independent methods, the authors were able to obtain a mean weighted error of 0.8% in their determination of neutron yield.

The fission rate in the target was determined in a chamber with a small solid angle, where fission fragments were detected by a silicon detector specially designed in the Radium Institute for a low level of the low-energy "tail" of the fission fragments spectrum. The solid angle of the chamber was varied in the range 0.375×10^{-4} to $10.946 \times 10^{-4} \times 4\pi$. The error in determination of the solid angle was 0.15%. In order to exclude any possible systematic error in the determination of the solid angles, the chamber was calibrated using a target of ^{241}Am, whose absolute activity was found by the coincidence method with an error of 0.1%.

The error in determining the fission rate in the target was 1%, the main part of which was due to the indeterminate nature of the californium losses while the target was in the chamber.

The resulting error in the determination of $\bar{\nu}$ was found to be 1.3%.

POLAR EMISSION OF LIGHT PARTICLES FORMED IN THE FISSION OF HEAVY NUCLEI

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S.S. Kovalenko, K.A. Petrzhak,
L.A. Pleskachevskij,
I.I. Tyutyugin

Studies were carried out on the angular and energy distributions of light particles formed in the spontaneous fission of ^{252}Cf. It was observed that light particles are ejected even at small angles to the axis of fragment divergence. The yields of light particles at small angles, in relation to the yield at 90° to the axis of fragment divergence were:

α particles: $\frac{Y\ (0°)}{Y\ (90°)} = 4.44 \pm 0.08\%$

For tritons: $\frac{Y\ (0°)}{Y\ (90°)} = 2.0 \pm 0.3\%$

Protons: $\frac{Y\ (0°)}{Y\ (90°)} = 121 \pm 14\%$

The relative yields of protons and tritons per 100 α particles for different angles are shown in the table:

Angle	Protons	Tritons	α particles
90°	1.3	10.5	100
45°	26.4	17.6	100
0°	36.5	4.9	100

The maximum in the energy distribution of α particles shifts smoothly from 15 MeV at 90° to 22.5 MeV at 0°. For protons the maximum shifts for small angles to 5.5 MeV, first increasing from 6.5 MeV at 90° to 8.5 MeV at 45°.

From the correlation between light and heavy fragment peaks for different angles it can be concluded that both types of fragment make an equal contribution to the "polar" emission of α particles.

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VI. Institute of Nuclear Physics, Ukrainian Academy of Sciences

NUCLEAR PHYSICS CONSTANTS OF NUCLEI INVOLVED IN THE THORIUM CYCLE

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(Paper submitted to the 2nd All-Union Conference on Neutron Physics)

An evaluation was made of neutron cross-sections at v = 2200 m/sec for all nuclei involved in the thorium cycle and also of those nuclear constants which are important for calculating the kinetics of the cycle. Excitation energies are given for thermal neutron capture and also decay energies and the energies of reactions with the emission of charged particles; likewise, values for the penetrability of the barriers in the case of charged particles from thermal neutron reactions. Weighted average values of the half-lives and of spontaneous fission are given as well as values of ν and other parameters.

NEUTRON CROSS-SECTIONS OF NEODYMIUM ISOTOPES

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(Paper submitted to the 2nd All-Union Conference on Neutron Physics)

The paper presents measurements of the energy dependence of the scattering cross-sections of the neodymium isotopes 142, 143, 144, 145, 146, 148, 150 and of the total cross-section of the isotope neodymium-143 in the 0.02-10 eV energy range. From an analysis of the total cross-section and the scattering cross-section for neodymium-143 by the least squares method it was possible to determine the negative level parameters:

$$E_r = -5.5 \pm 0.1 \text{ eV}; \quad q = 0.4375; \quad R' = 6.2 \pm 0.3;$$
$$\Gamma_n^o = 80 \pm 2; \quad \Gamma_\gamma = 73 \pm 3.$$

On the basis of the scattering cross-sections measurements, the optical radii R' were determined for all the above-mentioned neodymium isotopes: 5.8 ± 0.3; 6.2 ± 0.3; 5.4 ± 0.9; 5.1 ± 1.0; 5.4 ± 0.7; 7.9 ± 0.8; 5.5 ± 0.7. The energy dependence of the capture cross-sections of neodymium-143 was also determined as the difference $\sigma_\gamma = \sigma_t - \sigma_s$.

STUDY OF THE $^{68}Zn(n,\gamma)^{69g,m}Zn$ REACTION

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(Paper submitted to the 2nd All-Union Conference on Neutron Physics)

The activation method was used to obtain the neutron radiative capture cross-sections for the ^{68}Zn nucleus and to determine the probability ratios for isomer pair formation by the $^{68}Zn(n,\gamma)^{69g,m}Zn$ reaction in the 200-2500 keV energy range. The energy curve for the neutron capture cross-section was determined relative to the ^{235}U fission cross-section for fast neutrons. To normalize the cross-section the authors used the cross-section of the $^{68}Zn(n,\gamma)^{69g}Zn$ reaction for thermal neutrons and the fission cross-section of ^{235}U for thermal neutrons.

The experimental results are analysed on the basis of the statistical theory of nuclear reactions. The penetrabilities, $T_{lj}^{J\pi}$ needed to calculate the cross-sections from the statistical theory were calculated using the optical model of the nucleus. The density of states was calculated from the correlations of the Fermi-gas model. Better agreement between theory and experiment was obtained with the lowest of the values available in the literature: $D_{obs} = 8.6 \times 10^3$ eV and $\Gamma_\gamma(B_n) = 200$ mV. The calculated radiative capture cross-sections were found to be in good agreement with pairing correction factor $\delta = 0.5$ MeV and level density parameter $a = 8.93$ MeV^{-1}.

The authors study the influence of the choice of relationship between radiation width and energy on the behaviour of the capture cross-section, and discuss the reason for the discrepancy between the experimental and calculated isomer ratios for thermal neutrons.

NEUTRON CROSS-SECTIONS FOR VANADIUM IN THE THERMAL AND EPITHERMAL ENERGY RANGE

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The time-of-flight method was used on the VVR-M reactor of the Institute of Nuclear Research, Ukrainian Academy of Sciences, to measure the total neutron cross-sections of natural vanadium. Use was made of a neutron spectrometer with a mechanical neutron chopper. Table 1 gives the energy ranges, the energy resolution, and various parameters of the samples employed. Two sorts of pure metallic vanadium were used, the purity of neither being inferior to 99.7%. The samples were prepared in the form of rectangular tetragonal prisms, so that the measurements could be carried out for different thicknesses. Samples VI-VIII were obtained by electronic melting of vanadium of 99.7% purity, giving a final purity of better than 99.8%. The specifications of the samples are given in Table 2. Corrections for impurities are not greater than 0.01 barn.

The dependence of the total cross-sections on neutron time-of-flight is linear over the entire energy range and is expressed by the formula

$$\sigma_{tot} = \text{const.} + \sigma_a \sqrt{\frac{00253}{E}} ,$$

where the "constant" coincides with the scattering cross-section and is referred to in Table 1 by the designation $\sigma_{tot}(E \to \infty)$, and σ_a is equal to the neutron absorption cross-section for v = 2200 m/sec (see Table 1).

The total neutron cross-sections of natural vanadium as a function of neutron energy are shown in Table 1, together with the statistical measuring error. The maximum error due to the indeterminacy of the impurities may be not more than 0.02 barn. The error associated with the accuracy of the time-of-flight measurement may be 0.02 barn in the cross-section of scattering obtained by extrapolating the total cross-section to $E \to \infty$.

In view of the fact that natural vanadium is often employed as a calibrating sample in studies on the inelastic and elastic scattering of neutrons in matter, we not only measured the energy dependence of the total cross-sections but also compared the scattering cross-sections of vanadium in the epithermal range with the scattering cross-section of nuclei for which they are known with high accuracy (graphite, bismuth). The scattering cross-sections were measured in a 4π geometry, using a neutron counter filled with helium-3 and the time-of-flight method. Table 4 gives the characteristics of the samples used and Table 5 the scattering cross-sections obtained in the vanadium cross-section measurements relative to calibrated samples of bismuth and graphite.

The most probable value of the scattering cross-section for vanadium according to our direct measurements is (4.75 ± 0.03 barn). It should be noted that there is good agreement between the scattering cross-sections we obtained by direct measurement (4.75 ± 0.03 barn) and the scattering cross-sections obtained from the energy dependence of the total cross-section (4.75 ± 0.02 barn).

The upper limit of the total absorption width was determined from the total cross-section on the assumption that it does not change from one resonance to another and does not depend on the spin of the compound nucleus. The upper limit of Γ_a is 2 MeV for ^{51}V and 2.2 MeV for ^{50}V.

Table 1

Sample	Energy range (eV)	Resolution (msec/m)	Cross-sections (barns) at v = 2200 m/sec		
			σ_t	$\sigma(E \to \infty) = \sigma_s$	σ_a
VI	II0 - 0,I	0,5	-	4,7 ± 0,I	5,5 ± 0,6
VI	4 - 0,03	I,8	-	4,70±0,03	5,3I±0,05
VI	I,7 ± 0,007	3,5	I0,06±0,05	4,6±0,I	5,4 ± 0,I
VI	I,7 - 0,007	3,5	I0,II±0,06	4,79±0,06	5,37±0,09
VI	I,7 - 0,007	3,5	I0,00±0,05	4,8±0,I	5,28±0,I5
VII	I,7 - 0,007	3,5	I0,I2±0,08	4,75±0,03	5,I7±0,05

Table 2

Characteristics of vanadium samples

Sample	Weight (g)	Thickness (mm)	No. of nuclei $(cm^2 \times 10^{24})$	Enrichment %		Content (%)	Impurities
				^{50}V	^{51}V		
VI	23.4953	I5.8354	0.0II5	0.24	99.76	99.7	, , , 10^{-2} 5.10^{-3} 2.10^{-2} 8.10^{-2} 10^{-1}
VI	23.4953	9.0298	0.0085	-"-	-"-	-"-	-"-
VI	23.4953	26.7062	0,0I94	-"-	-"-	-"-	-"-
VII	28.6796	I5.370	0.0II0	0.24	99.76	99.7	C 0.02; N_2 0.0I; O_2 0.03; H_2 0.00I; Al 0.02; Fe 0.0I; Si 0.I8.

Table 3

Total neutron cross-sections of natural vanadium

Neutron energy E_n(eV)	Total cross-section σ_t (barn)	Neutron energy E_n(eV)	Total cross-section σ_t (barn)	Neutron energy E_n(eV)	Total cross-section σ_t (barn)
0,007	I4,6I±0,28	0,090	7,6I±0,0I7	50,0	4,75±0,II
0,008	I3,86±0,20	0,I0	7,40±0,0I9	60,0	4,7I±0,II
0,009	I3,00±0,I6	0,I5	6,89±0,020	70,0	4,73±0,II
0,0I0	I3,30±0,I3	0,20	6,58±0,03	80,0	4,65±0,II
0,0II	I2,79±0,II	0,25	6,36±0,04	90,0	4,75±0,II
0,0I2	I2,42±0,I0	0,30	6,34±0,04	I00,0	4,67±0,II
0,0I3	I2,24±0,09	0,40	6,09±0,04	II0,0	4,70±0,II
0,0I4	II,7I±0,08	0,50	5,9I±0,04		
0,0I5	II,39±0,075	0,60	5,79±0,04		
0,0I6	II,I4±0,07	0,70	5,68±0,04		
0,0I7	II,33±0,06	0,80	5,70±0,04		
0,0I8	II,I9±0,05	0,90	5,6I±0,04		
0,0I9	I0,78±0,04	I,0	5,60±0,04		
0,020	I0,78±0,03	I,5	5,37±0,04		
0,025	I0,02±0,03	2,0	5,35±0,05		
0,0253	I0,06±0,03	3,0	5,20±0,05		
0,030	9,57±0,02	4,0	5,I0±0,I0		
0,035	9,26±0,02	5,0	5,20±0,I0		
0,040	9,00±0,0I9	6,0	5,I7±0,I0		
0,045	8,76±0,0I7	7,0	5,I5±0,I0		
0,050	8,50±0,0I7	8,0	5,I0±0,I0		
0,055	8,28±0,0I6	9,0	5,I5±0,I0		
0,060	8,I6±0,0I6	I0,0	4,94±0,II		
0,065	8,00±0,0I6	I5,0	5,I0±0,II		
0,070	7,87±0,0I6	20,0	4,9I±0,II		
0,075	7,78±0,0I6	25,0	4,69±0,II		
0,080	7,70±0,0I6	30,0	4,9I±0,II		
0,085	7,66±0,0I6	40,0	4,8I±0,II		

Table 4

No. of measurement	Sample	Diameter (mm)	No. of nuclei per cm^2 x 10^{24}	$n\sigma_t$ at v=2200 m/sec	Purity %
I	metallic V VI	I0,0	0,00726	0,07	99,7
2	met. V VII	I0,0	0,037I	0,378	99,7
3	met. V VIII	I0,0	0,07II	0,725	99,7
4	reactor graphite CI	I0,0	0,0I70	0,I	-
5	reactor graphite CII	I0,0	0,035I	0,I5	-
6	metallic bismuth Bi	I0,0	0,0052I	0,05	99,99
7		I0,0	0,00092	0,056	-

Table 5

No. of measurement	Sample studied	Standard	σ_s (barns) standard	σ_s (barns), sample
1	VI	Bi	9,29(8)	4,73 ± 0,08
2	VII	Bi	9,29(8)	4,80 ± 0,08
3	VIII	Bi	9,29(8)	4,79 ± 0,08
4	VI	CI	4,74(9)	4,75 ± 0,02
5	VII	CII	4,74	4,71 ± 0,05
6	$V_2^{50}O_5$	V	4,74	7,5 ± 0,6

DETERMINING THE ABSORBED DOSE RESULTING FROM NEUTRON SCATTERING IN MATERIALS IRRADIATED IN NUCLEAR REACTORS

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(Article submitted to "Nuclear Constants")

The authors propose a method for determining the neutron component of absorbed dose in materials with $4 \leq Z \leq 83$ that does not require a knowledge of the shape of the neutron spectrum at the place of irradiation. To do this they consider the possibility of presenting the integral of energy transfer to a given material in the form of an expansion in the energy dependences of the cross-sections of the neutron detectors employed.

Calculations performed for 14 typical reactor neutron spectra showed that the ratio of the neutron components of absorbed dose in a given material and in hydrogen depend linearly on the proposed spectral parameters, i.e. the absorbed dose resulting from enturon scattering in the given material can be determined by using two neutron detectors (hydrogen and uranium-238 or hydrogen and sulphur) with a mean square error of not more than 2.3% (with a maximum deviation less than 7% in the various spectra).

When one detector is used to measure the rate of energy release from neutron scattering in hydrogen, the mean square error for the different materials is 3-13%, since for the 22 materials considered the above-mentioned ratio can be regarded as independent of the neutron spectrum within these limits (the maximum deviation does not exceed 6-26%, respectively).

VII. Physico-Technical Institute, Ukrainian Academy of Sciences

ELASTIC SCATTERING OF 14.7 MeV NEUTRONS BY SEPARATED ISOTOPES OF IRON, COBALT AND NICKEL

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(Paper submitted to the 2nd All-Union Conference on Neutron Physics)

Differential cross-sections for elastic scattering of 14.7 MeV neutrons by ^{54}, ^{56}Fe, ^{59}Co and ^{58}, ^{60}Ni nuclei were measured in a cylindrical geometry by the time-of-flight method with detection of the accompanying α particles. Corrections for attenuation, finite angular resolution and multiple scattering were made by the Monte Carlo method.

The experimental data are compared with the theoretical predictions obtained from a microscopic optical model of the nucleus. Using the χ^2 criterion the authors found the optimal sets of potential parameters and used them to calculate the mean square radii of distribution of the nuclear matter $<r^2>^{\frac{1}{2}}_m$.

The values of $<r^2>^{\frac{1}{2}}_m$ - $3.99^{+0.06}_{-0.17}\,\varphi$ (^{56}Fe), $3.94^{+0.07}_{-0.12}\,\varphi$(^{56}Fe); $4.18^{+0.11}_{-0.13}\,\varphi$(^{50}Co); $4.18^{+0.18}_{-0.12}\,\varphi$(^{56}Ni); $4.12^{+0.16}_{-0.12}\,\varphi$(^{60}Ni) - are in good agreement with the results of Pyle and Greenlees [1], obtained from an analysis of neutron elastic scattering by natural Fe and Ni and from the elastic scattering of 14.5 MeV protons by isotopes of iron and nickel.

REFERENCES

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VIII. Atomic Reactor Research Institute

FINE STRUCTURE IN THE NEUTRON SPECTRUM FOR SPONTANEOUS FISSION OF ^{252}Cf

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(Paper submitted to the 2nd All-Union Conference on Neutron Physics)

The time-of-flight method was used to measure the time distributions of neutrons from the spontaneous fission of ^{252}Cf in the 0.04-11 MeV energy range. Prompt fission gamma quanta were used as starting signals. To detect neutrons in the hard part of the spectrum ($E_n > 0.5$ MeV) a photoelectric multiplier with a plastic scintillator was employed in the "stop" detector. Neutrons of energy lower than 0.5 MeV were detected by fission and inelastic-scattering gamma rays produced in ^{235}U, which was used to convert low-energy neutrons into gamma rays. In this case, a stilbene crystal was used in the "stop" detector and a separator circuit was introduced to prevent the detection of neutrons undergoing scattering in the convertor; in this way, the time resolution was improved and the background due to random coincidences was decreased.

In the measured time resolutions, groups of monochromatic neutrons were observed with energies 0.084, 0.11, 0.16, 0.22, 0.42, 0.58, 0.76, 1.02, 1.27, 1.68, 2.6, 3.3, 4.1 MeV and (less reliably) 0.04, 0.057, 0.31, 2.84, 4.9, 6.1 MeV. Groups of neutrons of energy 0.084, 0.22, 0.41, 0.75, 1.2, 1.6, 2.6 MeV had been previously observed by other authors; the remaining groups have not been reported so far.

The results obtained in our work provide additional information regarding the mechanism of formation of fine-structure neutrons. In particular, if it is assumed that mono-energetic neutrons are emitted from fragments with residual excitation in the cascade with γ quanta and if we assume a lag in the neutrons relative to the γ-rays and in the γ,n cascades relative to the moment of fission, it follows from the data obtained that these delay times should not exceed a few nanoseconds. The results obtained also show that the γ quanta of fission can be used as start signals for accurately recording the instant of ejection of neutrons. This means that ^{252}Cf can be used with the time-of-flight method as a point source of fission spectrum neutrons, which is very convenient for the solution of numerous applied problems.

IX. All-Union Research Institute for Physico-technical and Radio-technical Measurements

EVALUATING THE EXPERIMENTAL CROSS-SECTIONS FOR FISSION OF ^{238}U, ^{237}Np AND ^{232}Th NUCLEI BY NEUTRONS OF ENERGY BETWEEN THE THRESHOLD VALUE AND 20 MeV

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(Paper submitted to the 2nd All-Union Conference on Neutron Physics)

Recent achievements in procedures for the reduction of fast neutron spectra, and the increasing reliability of experimental data on the energy dependence of cross-sections for threshold reactions, give reason to hope that the error in reduction can be correctly evaluated by using, first, data on the cross-section errors and, second, data on the errors in measuring the reaction rates in irradiated samples.

To determine the cross-section errors an analysis was made of experimental data on threshold reaction cross-sections for nuclear fission of ^{238}U, ^{237}Np and ^{232}Th, published towards the end of the year 1972, and data on the fission reaction cross-section for ^{235}U nuclei. An attempt was made to match the data of different authors in a neutron energy range from the threshold value up to 20 MeV and to get evaluated values of the cross-sections and their inaccuracies. The cross-section data are presented in tabular form.

IMPROVING THE EFFECTIVE THRESHOLD AND CROSS-SECTION VALUES OF CERTAIN REACTIONS IN ACTIVATION BY FAST NEUTRONS

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V.P. Yaryna

(Paper submitted to "Nuclear Constants")

Improved data are given for previously recommended values of effective thresholds and cross-sections for the following reactions:

^{237}Np(n,f) - E_{eff} = 0.58 MeV, σ_{eff} = 1560 mbarn;

^{103}Rh(n,n')- E_{eff} = 0.7 MeV, σ_{eff} = 920 mbarn;

^{115}In(n,n') - E_{eff} = 1.15 MeV, σ_{eff} = 286 mbarn;

^{51}Ni(n,p) - E_{eff} = 2.35 MeV, σ_{eff} = 335 mbarn;

^{32}S(n,p) - E_{eff} = 2.70 MeV, σ_{eff} = 246 mbarn, or E_{eff} = 3.0 MeV, σ_{eff} = 306 mbarn.

In performing the calculations the authors used a large number of reactor neutron spectra and supplementary data on reaction cross-sections. Tables are given showing the effective cross-sections of the above-listed reactions in the neighbourhood of the recommended threshold for all spectra; the same data are also presented in graphical form. Maximum values of the systematic error in the effective cross-sections are estimated, and cross-sections averaged for the ^{235}U fission neutron spectrum are also given. The principal reasons for the difference between the results given and the previously published results are discussed.