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I. Institute of Physics and Power Engineering

NEUTRON CROSS-SECTIONS OF DEUTERIUM IN THE ENERGY RANGE FROM 0.0001 eV TO 15 MeV

N.O. Bazazyants, A.S. Zabrodskaya, A.F. Larina, M.N. Nikolaev

Paper submitted to the scientific and technical publication "Yadernye konstanty" (Nuclear constants), No. 20

In the evaluations of the neutron cross-sections of deuterium that have been carried out abroad, significant discrepancies have been found between the results of various experiments designed to obtain data on the deuterium scattering cross-section in the region of low energies.

New experimental data that have recently appeared make it possible to resolve these contradictions and to select with significantly better justification the value of the total cross-section for deuterium in the low energy region.

In this context it was decided to re-evaluate the deuterium cross-sections for the SOKRATOR library. The present paper describes this evaluation and discusses the results obtained.

The bibliography used for the evaluation is listed in four tables with brief descriptions of the experimental methods.

References to sources of information not included in these tables are given in the list of references at the end of the paper.

At energies below 15 MeV only three interaction reactions of neutrons with deuterium are possible:

(1) Elastic scattering;

(2) Radiative capture;

(3) The (n,2n) reaction.

The cross-sections for these reactions and also the total cross-section for the interaction of neutrons with deuterium nuclei are discussed in the paper, which also gives the corresponding recommended curves.

The evaluation results are presented in the format of the SOKRATOR library. A 26-group system of constants is likewise given containing a null group corresponding to 14-MeV neutrons.

NEUTRON CROSS-SECTIONS OF NATURAL ERBIUM AND ITS STABLE ISOTOPES

S.M. Zakharova, L.P. Abagyan, N.O. Bazazyants,
Zh.A. Korchagina, L.V. Petrova, Eh.F. Sinitsa,
S.I. Tikhonova

Paper submitted to the scientific and technical publication "Yadernye konstanty" (Nuclear constants)

The paper consists of two parts. The first gives an evaluation of the energy dependence of the total cross-sections and of the cross-sections for capture and elastic and inelastic scattering and the elastic scattering anisotropy for natural erbium and its stable isotopes in the energy range 0.0253 eV–15 MeV. The exact behaviour of the cross-sections was first obtained by calculation: in the allowed resonance region on the basis of data on neutron resonance parameters, and in the forbidden resonance regions on the basis of statistical theory. The cross-sections obtained were then compared with experimental data on the energy dependence of cross-sections, on thermal cross-sections, and on resonance integrals of capture. A preliminary evaluation was made of the available data, and the results that seemed most reliable to us were selected.

The calculation in the allowed resonance region was done with the "Uran" program [1], in which the Breit-Wigner formula for an isolated resonance is used taking into account Doppler broadening of the resonance lines and interference between potential and resonance scattering. The calculation was performed to some energy E_{lim} below which no systematic gap in the levels is observed experimentally. The value of E_{lim} for each isotope was determined by analysis of the behaviour of the average distances observed between the levels $\bar{D}_{obs}$ and the average reduced neutron widths $\bar{G}_n^o$ depending on energy. The average values of the distributions of D_{obs} and G_n^o were compared with the theoretical distributions of Wigner and Porter-Thomas. The agreement between the observed and theoretical distributions in the energy range 0–E_{lim} also served as evidence for the absence of a systematic gap of levels in the energy region below E_{lim}.

The recommended average resonance parameters ($\bar{D}_{obs}$, $\bar{G}_\gamma$, S^o) were determined for the energy range 0–E_{lim}.

Above E_{lim} the cross-sections were calculated with the PRS-2M program [2], in which the formula of the Hauser-Feschbach statistical theory is used with the penetration factors of the nuclear surface from the optical model and the formula for level density from the Fermi-gas model. In this program the single-particle potential contains a term to account for spin-orbital interaction. The centrosymmetric optical potential was taken in the Woods-Saxon form. The parameters of the optical potential are independent of neutron energy. The values of these parameters (except r_0) were taken to correspond with the data of Ref. [3], in which the total cross-sections were calculated for a wide range of energies and mass numbers. The values for r_0 were chosen in such a way that the value of the force function, determined in accordance with the optical model, was approximately equal to the value obtained from the allowed resonance region. The values of the average resonance parameters $\bar{G}_\gamma$ and $\bar{D}_{obs}$ were also obtained from the latter region.

The cross-sections for the natural mixture of erbium isotopes were found by summation of the isotope cross-sections, taking their percentages into account. Comparison of the cross-sections obtained in this way with data from direct measurement of natural erbium cross-sections constituted an additional verification of the recommended cross-sections.

The second part of the paper contains 26, 21 and 80 group cross-sections for natural erbium and its stable isotopes, plotted on the basis of the energy dependence obtained for the cross-sections. These group cross-sections are intended for reactor calculations. The methods of plotting and averaging the group constants are the same as in Refs. [4] and [5].

The evaluated cross-sections are presented in the format of the SOKRATOR library [6]. The files of these evaluations can be obtained from the Obninsk Nuclear Data Centre.

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II. I.V. Kurchatov Institute of Atomic Energy

MEASUREMENT OF EFFECTIVE CROSS-SECTION FOR CALIFORNIUM-252 FISSION BY FAST REACTOR NEUTRONS

Eh.F. Fomushkin, E.K. Gutnikova, G.F. Novoselov, V.I. Panin

The effective cross-section for californium-252 fission by neutrons from a fast pulsed reactor were measured. For this purpose a device was set up in which a spring moved the glass plate detector relatively to the fixed layers of fissionable materials at the moment of the neutron pulse. Neptunium-237 was used as reference.

The cross-section for californium-252 fission by reactor neutrons obtained as a result of the measurements was 1.58 ± 0.14 b; within a margin of error this agrees with the data of other authors.

The anomalously high value of the cross-section confirms the significant effect of the neutron shell $N = 152$ on the fission characteristics of heavy nuclei. The lowering of fission barriers on passing through the shell $N = 152$ observed in curium isotopes also apparently occurs in californium isotopes.

MEASUREMENT OF THE CROSS-SECTION OF PLUTONIUM-240 FISSION ON NUCLEAR EXPLOSION NEUTRONS

Eh.F. Fomushkin, E.K. Gutnikova, G.F. Novoselov, V.I. Panin

A dielectric polymer film was used as the fragment detector in measuring the fission cross-sections for nuclear explosion neutrons by the time-of-flight method. The time base of the detector film relative to the layer of fissionable material was provided mechanically by a reel revolving at a rate of ~ 10^4 rev/min. The time resolution achieved in measuring the plutonium-240 fission cross-sections was 12 ns/m. The cross-section was measured by the relative method and the fission cross-section of plutonium-241 was used as reference. The films were chemically processed by the standard method. They were inspected, and the fission fragment tracks counted, with an optical microscope.

The plutonium-240 fission cross-section measured in the neutron energy range 2-200 keV has a resonance character. The results of averaging the cross-section by energy groups are given in the table.

E_{min}	E_{max}, keV	$\bar{\sigma}_f$, b	$\Delta\bar{\sigma}_f/\bar{\sigma}_f$, %
2	4	0,080	6,8
4	6	0,124	7,0
6	8	0,124	6,8
8	10	0,083	7,2
10	15	0,142	9,3
15	20	0,080	7,4
20	30	0,130	9,4
30	50	0,220	7,1
50	100	0,123	7,5
100	200	0,103	7,4

THE LEVEL POPULATION FOR ^{104}Pd AND ^{106}Pd IN INELASTIC SCATTERING OF FAST NEUTRONS FROM A REACTOR

L.I. Govor, A.M. Demidov, M.R. Akhmed, Kh.I. Shakarchi,
S. al-Najar, M.A. al-Amili, N. al-Asafi

The authors measured the gamma-ray spectra for fast neutrons inelastically scattered on ^{104}Pd and ^{106}Pd and evaluated the energies and relative intensities of 105 γ-transitions in ^{104}Pd (see Table 1) and 107 γ-transitions in ^{106}Pd. Schemes of the levels and γ-transitions of these nuclei were prepared.

A comparison was made between the experimental values for the level population in the (n,n'γ) reaction and values calculated with a statistical model. Agreement was found between the experimental and theoretical values for levels with the characteristics 0^+ and 2^+, whereas there was a discrepancy of a factor of 2 for levels 3^- and 4^+.

Energy and intensity of ^{104}Pd γ-lines for inelastic scattering of fast neutrons from a reactor

E_γ, keV	ΔE_γ, keV	I_γ, rel.	ΔI_γ	Place in scheme
215,6	0,2	0,7	0,2	
460,0	0,5	0,I6	0,03	I793,8 - I333,7
478,8	0,3	I,4	0,2	I820,8 - I34I,6
497,8	I,0	0,07	0,04	I820,8 - I323,5
539,4	0,5	0,I5	0,02	
555,74	0,07	I00,0		555,7 - 0
6I7		0,32	0,I0	I94I,2 - I323,5
623		0,I4	0,04	2445,4 - I820,8
727,4	0,5	0,I6	0,04	
740,62	0,I2	0,79	0,07	2082,2 - I34I,6
758,69	0,I2	0,84	0,07	2082,2 - I323,5
767,77	0,I0	I2,I	0,6	I323,5 - 555,7
777,93	0,I0	4,2	0,2	I333,7 - 555,7
785,8I	0,I0	9,2	0,5	I34I,6 - 555,7
8I8,5	0,9	0,059	0,0I5	
84I,0	0,7	0,II	0,03	2I8I,6 - I34I,6
858,0I	0,I5	0,80	0,07	2I8I,6 - I323,5
879,3	0,8	0,067	0,0I6	
889,4	0,6	0,I2	0,04	
895,I	I,0	0,05	0,02	
902,4	0,6	0,I3	0,03	2244,7 - I34I,6
9I0,2	0,4	0,22	0,04	2992,4 - 2082,2
922,5	0,8	0,I3	0,05	2265,3 - I34I,6
925,9	0,2	0,65	0,09	2249.4 - I323,5
934,8	0,9	0,062	0,0I5	2276,7 - I34I,6
94I,78	0,I5	0,74	0,06	2265,3 - I323,5
953,9	0,7	0,076	0,0I6	3I35,8 - 2I8I,6
974,4	0,2	0,40	0,05	
978,3	0,4	0,22	0,03	2799,I - I820,8
996,0	0,7	0,I0	0,03	2338,3 - I34I,6
I028,I	0,9	0,09	0,03	235I,6 - I323,5

Continuation of table

E_γ, keV	ΔE_γ, keV	I_γ, rel.	ΔI_γ	Place in scheme
1077,2	I,0	0,08	0,03	
1088,I	0,5	0,14	0,03	
1121,6	0,6	0,30	0,I0	
1132,I	0,3	0,38	0,04	2465,8 - I333,7
1167,56	0,I3	I,00	0,07	
1179,3	0,2	0,49	0,05	252I,I - 134I,6
1230,7	0,2	0,4I	0,08	2572,5 - I34I,6
1238,05	0,09	4,9	0,3	I793,8 - 555,7 I792,9 - 555,7
1247,4	0,5	0,24	0,05	2570,9 - I323,5
1265,09	0,1	4,0	0,3	I820,8 - 555,7
1271,69	0,I6	0,59	0,05	2613,3 - I34I,6
1284,I	0,4	0,I8	0,03	3I04,9 - I820,8
1300,0	0,8	0,I0	0,03	264I,7 - I34I,6
I318,2	0,3	0,30	0,03	264I,7 - I323,5
1341,73	0,09	6,0	0,4	I34I,6 - 0
1372,6	0,9	0,09	0,03	27I4,5 - I34I,6
138I,4	0,8	0,10	0,03	27I4,5 - I333,7
1390,I	I,I	0,07	0,03	
I397	line boundary	0,26	0,03	
I409	line boundary	0,26	0,03	
I450,5	0,4	0,I9	0,03	2774,0 - I323,5
I480,4	I,0	0,08	0,03	
I5I4,9	I,0	0,08	0,03	
I526,4	0,2	0,60	0,05	2082,2 - 555,7
I542	line boundary	0,16	0,03	2866 - I323,5
I55I,0	0,7	0,II	0,03	2874,5 - I323,5
I583,0	0,2	0,77	0,07	2I38,7 - 555,7
1599,9	0,4	0,I8	0,03	2923,4 - I323,5
I6I2,6	I,4	0,04	0,02	
I622,8	0,2	I,36	0,I4	2178,5 - 555,7
I625,9	0,4	0,31	0,06	2I8I,6 - 555,7
I637,5	0,I4	3,2	0,3	2I93,2 - 555,7
[illegible]	[illegible]	0,I5	0,03	3000,3 - I323,5

Contimuation of table

E_γ, keV	ΔE_γ, keV	I_γ, rel	ΔI_γ	Place in scheme
I688,92	0,I4	I,38	0,I4	2244,7 - 555,7
I696,8	0,6	0,I3	0,03	3020,3 - I323,5
I720,7	0,3	0,35	0,04	2276,7 - 555,7
I762	line boundary	0,I8	0,03	3086 - I323,5
I782	line boundary	0,59	0,I0	2338,3 - 555,7
I794	line boundary	0,48	0,06	I793,8 - 0
				2351,6 - 555,7
I8I2,5	0,7	0,I2	0,03	3135,8 - I323,5
I839,7	0,8	0,I	0,03	
I895,8	0,6	0,I3	0,03	
I900,8	0,2	0,55	0,06	2456,6 - 555,7
I909,8	1,0	0,08	0,03	2465,8 - 555,7
I976,2	0,5	0,I6	0,03	2521,1 - 555,7
I977,4	0,3	0,52	0,06	2533,1 - 555,7
2016,9	0,3	0,33	0,04	2572,5 - 555,7
2070,0	0,3	0,43	0,05	2625,7 - 555,7
2I08,5	0,7	0,I4	0,03	
2I38,7	0,3	0,35	0,04	2694,4 - 555,7
2I84,7	I,4	0,05	0,02	
22I0,6	0,3	0,43	0,05	2766,3 - 555,7
2232,8	I,I	0,07	0,02	
2276,9	0,3	0,46	0,05	2276,7 - 0
2338,3	0,3	0,3I	0,04	2338,3 - 0
2362,4	0,4	0,3I	0,06	29I7,9 - 555,7
2420	line boundary	0,2I	0,03	2976 - 555,7
2452,2	0,7	0,I4	0,03	3007,7 - 555,7
2523,6	0,7	0,I2	0,03	3079,3 - 555,7
2534,4	0,7	0,I4	0,03	
2540,4	0,6	0,I5	0,03	3096,I - 555,7
2593,I	0,6	0,I5	0,04	
2598,8	I,0	0,I0	0,04	
2623,6	0,4	0,54	0,06	3179,3 - 555,7
2705,5	0,7	0,I3	0,03	
2715,8	0,8	0,I7	0,04	
2726,I	I,I	0,09	0,03	328I,5 - 555,7
2916,2	1,0	0,II	0,03	
300I,6	1,2	0,08	0,03	3000,3 - 0
3007,6	I,0	0,1	0,03	3000,7 - 0
3013,5	0,9	0,I2	0,03	
3032,0	0,8	0,I4	0,04	
328I,3	I,I	0,07	0,03	328I,5 - 0

LEVEL POPULATION FOR ^{92}Mo IN INELASTIC SCATTERING OF FAST NEUTRONS FROM A REACTOR

A.M. Demidov, L.I. Govor, O.K. Zhuravlev, M.M. Komkov, V.A. Starostin, I.B. Shukal

Paper presented at Third Conference on Neutron Physics

Table 1

Energies and intensities of γ-lines of ^{92}Mo from the $(n,n'\gamma)$ reaction for fast neutrons from a reactor

E_γ, keV	I_γ, rel. $\vartheta = 90°$	Place in scheme
148,6 ± 0,6	0,7 ± 0,2	2759,4 - 2610,8
243,6 ± 0,3	17,3 ± 1,0	2525,0 - 2281,6
304,0 ± 0,5	1,5 ± 0,2	3366,4 - 3062,2
329,2 ± 0,7	1,3 ± 0,2	2610,8 - 2281,6
361,4 ± 0,8	1,0 ± 0,2	3366,4 - 3004,8
479,8 ± 0,2	4,0 ± 0,6	3004,8 - 2525,0
537,3 ± 0,2	5,9 ± 0,5	3062,2 - 2525,0
772,0 ± 0,2	25,9 ± 1,5	2281,6 - 1509,6
941,7 ± 0,6	0,55 ± 0,10	3944,8 - 3004,8
946,3 ± 0,8	0,6 ± 0,2	4008,5 - 3062,2
1009,4 ± 0,4	2,2 ± 0,4	2519,0 - 1509,6
1340,0 ± 0,2	6,5 ± 0,5	2849,6 - 1509,6
1509,0 ± 0,1	100	1509,6 - 0,0
1581,8 ± 0,7	0,80 ± 0,15	3091,4 - 1509,6
2033,0 ± 0,4	2,2 ± 0,3	3542,7 - 1509,6
2113,0 ± 0,3	1,6 ± 0,3	3622,6 - 1509,6
2179,3 ± 0,8	0,6 ± 0,2	3688,9 - 1509,6
2417,6 ± 1,5	0,3 ± 0,1	3927,2 - 1509,6
3091,4 ± 0,5	2,50 ± 0,15	3091,4 - 0,0
3927,2 ± 1,0	0,35 ± 0,15	3927,2 - 0,0
3944,8 ± 1,0	0,40 ± 0,15	3944,8 - 0,0
4022,1 ± 0,7	0,75 ± 0,25	

Table 2

Experimental and theoretical level populations for ^{92}Mo in the $(n,n'\gamma)$ reaction for fast neutrons from a reactor

E_{lev}, keV	I^π	P_s rel. (exp)	P_s^M (theor.), rel.
1509,6	2^+	73,0 ± 4,0	73,0
2281,6	4^+	9,5 ± 2,2	11,9
2519,0	0^+	2,2 ± 0,4	3,8
2525,0	5^-	6,7 ± 1,5	2,5
2610,8	6^+	0,9 ± 0,5	0,54
2759,4	8^+	1,0 ± 0,3	0,27
2849,6	3^-	5,9 ± 0,5	5,2
3004,8	4^+	2,4 ± 0,8	2,7
3062,2	4^+	3,6 ± 0,5	2,7
3091,4	2^+	3,9 ± 0,4	4,1

The P_s values are given after deduction of the cascade population.

III. V.G. Khlopin Radium Institute

UPPER LIMIT OF CROSS-SECTION OF ^{226}Ra FISSION BY THERMAL NEUTRONS

I.M. Kuks, Yu.A. Nemilov, V.A. Nikolaev, E.V. Seleznev,
Yu.A. Selitskij, V.B. Funshtejn

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The aim of the work was to verify the findings published in Ref. [1], which reported the comparatively large cross-section of 4.7 mb for fission of ^{226}Ra by thermal neutrons, and a symmetrical distribution of the fragment masses. Using mica detectors and glass detectors with an aluminium filter it was found by the authors of the present paper that in a flux of thermal neutrons the upper limit for the radium fission cross-section is 0.05 mb. This value is in agreement with that given earlier in Ref. [2]. The spectrum of diameters of fragment tracks in the glass detector, analogous to the spectrum of kinetic energy, was found to be asymmetrical and was probably due to the fission of uranium impurities in the radium target. Thus the results of Ref. [1] were not confirmed in this experiment.

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SCATTERING OF 4.7-MeV NEUTRONS ON Al AND Fe

L.S. Lebedev, Yu.A. Nemilov, A.V. Orlovskij

By now much material has been collected on inelastic scattering of neutrons with an initial energy $E_n = 14$ MeV, but little work has been done on neutrons with lower initial energies.

This paper presents the results of measurements of neutron scattering spectra on Al and Fe when $E_n = 4.7$ MeV at three scattering angles: 20°, 97° and 120°.

We used the time-of-flight method based on a pulsed operating regime of the EhG-5 accelerator, which had the following parameters: pulse repetition frequency 2 MHz, average current on target 1 μA, resolution in elastic scattering peak 3-4 ns, distance scatterer - target 10 cm, scatterer - detector 250-310 cm. The scatterers were aluminium and iron cylinders with the dimensions l = 4 cm and d = 5 cm. The detector was a plastic scintillator of d = 10 cm and h = 3 cm coupled with an FEhU-63 photomultiplier. The detector was placed in a mobile shield made of paraffin with boron carbide and was also surrounded with a 5-cm layer of lead. The overall dimensions of the shield were 80 x 120 cm. A standard titanium-deuterium target with a thickness of 1 mg/cm^2 was used.

The energy calibration of the device was performed using ^{252}Cf spontaneous fission neutrons, the spectrum of which was taken in the form: $N(E) = N_o e^{-0.88E} \, \mathrm{sh} \sqrt{2E}$ [3]. As detector of the fission fragments giving zero time we used a scintillating film with a thickness of 1 mg/cm^2 together with an FEhU-36 photomultiplier, in front of which the ^{252}Cf source was placed at a distance of 0.3 mm. The calibration was performed over the neutron energy range 0.7-6 MeV with an accuracy of 3-4%, which was taken into account in the final result. After calibration we measured the spectra of neutrons with $E_n = 4.7$ MeV which were scattered on Fe and Al at the three angles (laboratory system of co-ordinates): 20°, 97° and 120°. After these measurements had been completed the calibration was checked. The spectra of neutrons scattered at an angle of 120° are given in the figure.

In determining the inelastic scattering cross-sections the cross-sections for elastic interaction were presumed to be known, their values being taken from Ref. [4]. The results of the cross-section measurements for the identified levels are given in the table.

^{27}Al

Scattering angle	Scattering cross-section (mb/sr) Level 1.01 MeV	Level 2.2 MeV	Level 3 MeV
20°	8,3 ± 0,5	4,3 ± 0,3	4,5 ± 0,4
97°	9,4 ± 0,6	3,9 ± 0,3	4 ± 0,3
120°	12 ± 0,8	4,2 ± 0,3	3,5 ± 0,3

Fe

Scattering angle	Scattering cross-section (mb/sr) Level 0.84 MeV	Level 2.65 MeV	Total cross-section for inelastic scattering with E_n = 1-4 MeV
20°	15 ± 0,9	9 ± 0,5	60 ± 3,5
97°	13 ± 0,8	II ± 0,7	52 ± 3
120°	I4 ± 0,9	8,8± 0,5	54 ± 3

Thus the scattering is practically spherically symmetrical for the levels identified. It is striking that the spectra of neutrons scattered on ^{27}Al lack a noticeable level with an energy of 2.73 MeV. However, in a study of inelastic scattering of protons in the energy range E_p = 5-6.5 MeV [5] this level appeared clearly; the same study also revealed a significant energy dependence of proton inelastic scattering. Possibly the absence of this level in our results is due to a strong energy dependence of the formation cross-section of this level.

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IV. Atomic Reactor Research Institute

TOTAL NEUTRON CROSS-SECTION AND NEUTRON RESONANCE PARAMETERS OF ^{241}Am IN THE ENERGY RANGE 0.004-30 eV

T.S. Belanova, A.G. Kolesov, V.A. Safronov, S.M. Kalebin,
V.S. Artamonov, R.N. Ivanov, G.V. Rukolajne

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(Atomic energy)

On the ITEhF heavy-water reactor the transmissions in the energy range 0.004-8 eV were measured by the time-of-flight method with a resolution of 140 ns/m. The neutron pulse was formed by a selector chopper with synchronously revolving rotors suspended in a magnetic field [2]. Analogous measurements were made on our Institute's SM-2 reactor up to an energy of 30 eV. The experimental conditions and procedure for processing the results are described in detail in Ref. [1]. The present paper generalizes the results of the experiments mentioned above.

The AmO_2 powder samples with a thickness of 0.63×10^{21} and 3.3×10^{21} at/cm^2 contained 99.99% of the isotope ^{241}Am. The resonance parameters for 13 levels up to 8 eV were calculated by the form method using the single-level Breit-Wigner formula; two of these - 2.538 and 6.65 eV - were discovered for the first time. In order to make the calculated transmission values agree with the experimental values in the thermal region a negative level $E_o = -0.425$ eV was introduced. The existence of five powerful levels at $E_o = 2.36$, 4.40, 6.78, 7.97 and 16.02 eV was not confirmed. Analysis of the square root distribution of the neutron widths given showed that it corresponded to a Porter-Thomas distribution with a degree of freedom $\nu = 1.07 \pm 0.23$. The best agreement of this distribution with the experimental histogram was obtained for a level number n = 44 and $2g\Gamma_n = 0.096$ MeV. It follows from this that the loss of six weak levels below 26 eV must be postulated. Wigner distributions for one system of levels describe the histogram of the experimental distribution better, although two level systems must exist in the ^{241}Am nucleus. The experimental data were analysed for correlation of a long-range order, using the Δ_3 test of Dyson and Metha [3] for the orthogonal assembly. The experiments gave $\Delta_3 = 0.367$; the theoretical value for two level systems is $\Delta_3 = 0.723 \pm 0.219$, for one system it is $\Delta_3 = 0.362 \pm 0.11$. By analysis of the statistical properties of the nucleus an average level distance $\bar{D}_o = 0.67 \pm 0.1$ eV, $\overline{2g\Gamma_n} = 0.102$ MeV, $S_o = (0.76 \pm 0.18) \times 10^{-4}$ was obtained. The numerical data on the total cross-section were transmitted to the Nuclear Data Centre, and the resonance parameters were published in Ref. [1].

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Parameters of ^{241}Am neutron resonances

E_o, eV	Γ, MeV	$2g\Gamma_n$, MeV
-0,425	40	$2g\Gamma_n^o$ = I,0
0,306±0,002	45±I	0,0556 ± 0,0004
0,573±0,004	43±I	0,0928 ± 0,00I6
I,268±0,004	4I±2	0,330 ± 0,0I6
I,9I6±0,005	46±2	0,I07 ± 0,002
2,538±0,008	4I±2	0,070 ± 0,00[illegible]
2,58I±0,009	38±2	0,I50 ± 0,004
3,956±0,009	28±3	0,230 ± 0,008
4,947±0,0I0	3I±5	0,I76 ± 0,005
5,390±0,0I2	38±7	0,844 ± 0,II4
6,I00±0,0I3	42±I4	0,II6 ± 0,005
6,650±0,0I5		0,05 ± 0,03
7,53 ±0,02		0,07 ± 0,04
8,I7 ±0,02	42±5	0,096 ± 0,004
9,II ±0,02	48±3	0,358 ± 0,006
9,84 ±0,03	48±3	0,370 ± 0,007
I0,II ±0,03		0,025 ± 0,004
I0,39 ±0,03	45±4	0,294 ± 0,007
I0,99 +0,04	52±4	0,0382 ± 0,003
II,58 ±0,05		0,0I8 ± 0,003
I2,06 ±0,06		0,007 ± 0,003
I2,86 ±0,06	44±5	0,II6 ± 0,009
I4,32 ±0,06		0,066 ± 0,0I2
I4,66 ±0,07	44±5	2,30 ± 0,I3
I5,66 ±0,07	32±I2	0,2I5 ± 0,0I2
I6,35 ±0,07	44±5	I,I85 ± 0,033
I6,8I ±0,07	3I±8	0,575 ± 0,020
I7,69 ±0,07	40±I0	0,373 ± 0,0I6
I8,09 ±0,07		
I9,39 ±0,07	37±I2	0,I82 ± 0,0I6
20,28 ±0,07		0,050 ± 0,0I0
20,84 ±0,09		0,064 ± 0,0II
2I,72 ±0,08		0,067 ± 0,0I2
22,74 ± 0,09		0,070 ± 0,0I2
23,08 ± 0,09		0,39 ± 0,05
23,33 ± 0,09		0,40 ± 0,05
24,I7 ± 0,09		I,27 ± 0,08
25,06 ± 0,I0		
25,60 ± 0,I0		I,2I ± 0,08
26,50 ± 0,I0		
26,67 ± 0,I0		
27,52 ± 0,I0		
27,65 ± 0,I0		
28,3I ± 0,II		0,40
28,82 ± 0,I2		0,35
29,43 ± 0,I2		0,6I

THE TOTAL NEUTRON CROSS-SECTION AND NEUTRON RESONANCE PARAMETERS OF ^{243}Am IN THE ENERGY RANGE 0.4-35 eV

T.S. Belanova, A.G. Kolesov, V.A. Poruchikov, G.A. Timofeeva, S.M. Kalebin, V.S. Artamonov, R.N. Ivanov

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On the SM-2 reactor the ^{243}Am transmissions for neutrons with energies between 0.4 and 30 eV were measured by the time-of-flight method with a path length of 92 m and a resolution of 70 ns/m. The neutron burst was formed by a spectrum with three synchronously turning rotors suspended in a magnetic field. The samples of AmO_2 powder contained 79.8% americium. The isotopic content of the samples was 96.9% ^{243}Am, 3.32% ^{241}Am and 0.08% ^{244}Cm. The samples were placed in an aluminium cylinder with a wall thickness of 1 mm and annealed in an oxygen atmosphere at 400°C for 3 hours. The sample thicknesses were 0.8 mm (0.45×10^{21} at/cm^2) and 14 mm (7.9×10^{21} at/cm^2).

A battery of helium counters was used as a neutron detector. A statistical accuracy of 0.5-1.5% was maintained in the measurements. The error also contained a component connected with the determination of the shape of the resolution function, and the neutron background varied between 0.7 and 4%. The measured transmissions were corrected for scattering on the oxygen (up to 3% in a thick sample) and for the ^{241}Am contribution.

The results were processed on a BEhSM-6 computer. The numerical material on $\sigma_t(E)$ was transmitted to the Nuclear Data Centre. The resonance parameters for 48 levels were obtained using the single-level Breit-Wigner formula and the form method in the region below 26 eV and the area method above 26 eV. The measurements did not confirm the existence of a weak level with an energy of 22.011 eV, but a weak level with E_0 = 31.49 eV was found. The value of the total resonance integral was calculated as 1740 b. The analysis of the statistical properties of the ^{243}Am nucleus yielded average distances between the levels of $\bar{D}_0 = 0.71 \pm 0.1$ eV and a force function $S_0 = (0.89 \pm 0.19) \times 10^{-4}$. The potential scattering cross-section could not be determined owing to a 20% impurity of reactive elements in the sample.

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Neutron resonance parameters for ^{243}Am

E, eV	G, MeV	$2g\Gamma_n$, MeV	σ_o, b
0,4I6±0,002	39 ± 2	0,00089±0,00005	67 ± 2
0,977±0,004	37 ± 2	0,0I34 ±0,003	480 ± 20
I,355±0,0043	56 ± I	0,890 ±0,007	I5I30±300
I,743±0,005	39 ± I	0,208 ±0,002	3980±50
3,I33±0,008	47 ± 3	0,0I2 ±0,003	I00±I0
3,424±0,0I7	45 ± 2	0,253 ±0,008	2I30±I60
3,844±0,0I7	22 ± 5	0,009 ±0,00I	I37±30
5,120±0,03	63 ± 2	0,260 ±0,006	I040±45
6,55I±0,04	50 ± 3	0,794 ±0,044	3I00±380
7,063±0,04	46 ± 3	0,072 ±0,0II	286±I4
7,858±0,05	36 ± 9	I,580 ±0,I36	7330±I800
8,39 ±0,02	40	0,0I0	40
8,77 ±0,02	46	0,II3	360
9,32 ±0,02	43	0,I33	430
I0,3I ±0,03	47	0,433	II50
I0,87 ±0,04	40	0,0I3	40
II,27 ±0,05	49	0,267	630
II,68 ±0,06	35	0,094	290
I2,I2 ±0,06	4I	0,I52	400
I2,87 ±0,06	43	2,20	5000
I3,I5 ±0,06	45	I,00	2200
I5,I2 ±0,07	33	0,070	I80
I5,39 ±0,07	37	0,36	3I00
I6,20 ±0,07	39	0,5I2	I060
I6,56 ±0,07	27	0,I74	5I0
I7,84 ±0,07	35	0,2I0	449
I8,I4 ±0,07	27	0,046	I20
I9,50 ±0,07	27	0,I93	470
I9,88 ±0,07	40	0,085	I40
20,94 ±0,08	29	0,54	I200
2I,09 ±0,08	I6	0,86	3200
2I,85 ±0,09	27	0,I4	300
22,0II±0,09			
22,59 ±0,09	33	I,00	I700
22,72±0,09	I9	0,65	2200
24,39±0,09	(22)	0,73	2400
25,38±0,I0	(40)	0,I4	I80
26,30±0,I0		0,06	80
26,75±0,I0	(30)	I,I6	I900
27,34±0,I0	(30)	0,43	500
28,73±0,I0	(30)	0,97	II45
29,29±0,II	(30)	0,68	I000
30,I2±0,I2	(30)	0,486	696
3I,06±0,I2	(30)	0,7	968
3I,49±0,I3	(30)	0,I2	I6I
32,43±0,I4	(30)	0,88	II40
33,I9+0,I4	(30)	I,9	2350
33,92±0,I5	(30)	0,8	986

NEUTRON RESONANCES OF THE ISOTOPES ^{244}Cm, ^{245}Cm, ^{246}Cm AND ^{248}Cm

T.S. Belanova, Yu.S. Zamyatnin, A.G. Kolesov,
N.G. Kocherygin, S.N. Nikol'skij, V.A. Safonov,
S.M. Kalebin, V.S. Artamonov, R.N. Ivanov

Paper submitted to journal "Atomnaya ehnergiya"
(Atomic energy)

Neutron choppers with synchronously revolving rotors suspended in a magnetic field were installed at the ITEhF and NIIAR reactors for measuring the transmission of samples containing the curium isotopes 244, 245, 246 and 248. The resolution of the spectrometers was 70 ns/m on the 92-m base at NIIAR [1] and 140 ns/m on the 50-m base at ITEhF [2].

A dehydrated powder of stable curium oxide with known oxygen content (Cm_2O_3) was studied. Before being filled into the target the powder was annealed at a temperature of 900-1100°C. Two samples were prepared with different curium isotope contents. The sample characteristics are given in Table 1. Sample 1 contained the impurities ^{243}Am (2%) and ^{240}Pu (1.6%); sample 2 contained 0.13% ^{243}Am and 0.8% ^{240}Pu.

The transmissions of the samples were measured in the energy region above 0.5 eV; a statistical accuracy within 1-2% was maintained, and the neutron background varied between 0.5 and 2%. Correction was made for the scattering of neutrons on oxygen.

The resonance parameters were calculated by the form and area method using the single-level Breit-Wigner formula. The resolution function was not approximated by an analytical expression, but directly calculated by computer, taking into account the factors that characterize the resolving power of the device. The location of the resonances E_o, and the values of the neutron ($2g\Gamma_n$) and total (Γ) widths were determined.

1. Curium-244: Measurements were carried out for several ^{244}Cm sample thicknesses, the greatest being $n_o = 0.24 \times 10^{22}$ atoms/cm^2. Table 2 gives the resonance parameters for ^{244}Cm up to 171 eV. In processing the resonances by the area method the radiation width Γ_γ was taken to be 37 MeV.

The average distance between levels $\bar{D} = 14.6 \pm 2.2$ eV and the force function $S_o = (0.68 \pm 0.30) \times 10^{-4}$ were calculated. It was also shown that for ^{244}Cm the neutron widths quoted followed the Porter-Thomas distribution for one degree of freedom, while the distances between levels followed the Wigner distribution.

2. Curium-245: Table 3 gives tentative values of the resonance parameters for the isotope ^{245}Cm. A sample with thickness 0.26 x 10^{21} atoms/cm^2 was used. Up to an energy of 50 eV 32 levels were found. They were all calculated by the area method, it being taken that Γ_γ = 40 MeV.

3. Curium-246: For a ^{246}Cm sample 0.21 x 10^{22} atoms/cm^2 thick 6 levels were identified in the energy range up to 157 eV. The resonance parameters were calculated by the form and area method, taking Γ_γ = 37 MeV. In the present paper the level 26.88 eV is not identified unambiguously, but attributed to the isotope ^{246}Cm. It may also be ascribed to ^{248}Cm. The parameters calculated for it in this case are Γ_n = 36.7 ± 3.1 MeV, Γ_n = 21.7 MeV; the neutron width agrees with the Γ_n = 19.6 ± 0.9 MeV of Ref. [3], in which this level is assigned to ^{248}Cm.

4. Curium-248: The resonance parameters of the levels of ^{248}Cm for energies up to 100 eV are given in Table 5. The sample thickness was 0.27 x 10^{21} atoms/cm^2. A value Γ_γ = 40 MeV was chosen in processing the resonances by the area method.

A new resonance with an energy of 84 eV is given for ^{248}Cm. The level with an energy of 35.0 eV [3] was not found. The neutron width Γ_n = 3.5 ± 0.3 MeV of the 35.0 eV resonance in ^{244}Cm [3] does not permit the conclusion that ^{248}Cm has a level of the same energy; it should apparently be ascribed to ^{244}Cm. In measurements taken in an atomic explosion [4], no resonance with an energy of 35.0 eV was found for ^{248}Cm.

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Table 1

Sample characteristics

Number of sample	Weight, mg	Isotopes (%)					
		^{242}Cm	^{244}Cm	^{245}Cm	^{246}Cm	^{247}Cm	^{248}Cm
I	82,8	0,3I	88,62	9,57	I,49	-	-
2	II6,4	-	39,28	0,47	5I,85	I,6I	6,79

Table 2

Resonance parameters of ^{244}Cm

E_o, eV	Γ, MeV	$Γ_n$, MeV	E_o, eV	$Γ_n$, MeV
7,67	44 ± 3	I0,4 ± 0,4	85,6	26,0 ± 4,8
I6,77	37 ± 5	I,90± 0,30	95,5	7,8 ± 2,2
22,85	36 ± I0	0,84±0,I0	I32	I6 ± 8
35,0	33 ± 5	5,I ± 0,8	I39	2,2 ± 0,9
52,8	-	0,56± 0,I5	I7I	3,6 ± I,8
69,8	-	0,44± 0,25		

Table 3

Resonance parameters of ^{245}Cm

E_o, eV	$2Γ_n$, MeV	E_o, eV	$2Γ_n$, MeV	E_o, eV	$2Γ_n$, MeV
I,93	-	25,0	2,4±0,4	36,3	3,6±I,8
4,69	I,73±0,35	26,9	-	40,9	I,8±0,9
9,25	0,32±0,05	27,I	I,0±0,3	42,9	3,0±I,5
II,4	0,50±0,20	29,6	4,2±0,7	43,5	-
I4,0	0,25±0,08	3I,4	0,5±0,2	44,9	I,7±0,5
I5,9	-	32,4	0,4±0,2	47,8	5,7±I,4
2I,6	2,6 ±0,4	35,2	-	49,2	2,2±I,2
				50,5	I,8±0,7

Table 4

Resonance parameters of ^{246}Cm

E_o, eV	Γ, MeV	$Γ_n$, MeV	E_o, eV	$Γ_n$, MeV
4,32	27 ± 2	0,34±0,0I	84,5	-
I5,29	28 ± 3	0,52±0,0I	9I,5	9,9±2,5
26,88*	36 ± 3	2,85±0,04	I57	34,I±7,6

* Possibly ^{248}Cm.

Table 5

Resonance parameters of ^{248}Cm

E_o, eV	Γ, MeV	$Γ_n$, MeV	E_o, eV	$Γ_n$, MeV
7,26	36±3	I,90±0,04	84	-
75,6	-	I02,5 ±I3,6	98,6	I69 ± I8

V. Ukrainian SSR Academy of Sciences
Nuclear Research Institute

MEASUREMENT OF THE ENERGY DEPENDENCE OF η FOR ^{233}U IN THE REGION 0.02-1 eV

V.A. Pshenichnyj, A.I. Blanovskij, N.L. Gnidak, E.A. Pavlenko

Exact data on the effective number of fission neutrons η for ^{233}U in the low-energy region are important for planning slow-neutron breeder reactors, as the fundamental indeterminacy of the breeding ratio in such reactors is due to the indeterminacy of η for ^{233}U. For this reason the energy dependence of η for ^{233}U in the range 0.02-1 eV was determined, with an accuracy of 1-2%, on the Institute's WWR-M reactor. The measurements were made by the time-of-flight method with a resolution of ~ 12 μs/m and normalized to the value at E = 0.0253 eV, it being taken that at this point $\eta = 2.297$. The neutron beam from the reactor was transformed into a pulsed beam by a mechanical chopper, the rotor of which was 300 mm in diameter and had a slit width of 2 mm. The sample and detectors were located at a distance L = 503 $\pm$ 5 cm from the chopper. The fission neutrons were recorded in a geometry close to 2π by a battery of 50 SNM-37 helium counters with a moderator. In order to reduce the neutron lifetime a cadmium screen was placed between the moderator and the counters. The incident neutron flux was measured from the γ-rays of neutron capture by cadmium or indium samples. Such (n,γ) detectors consist of a NaI(Tl) crystal with ∅ 70 x 70 mm and an FEhU-49 photomultiplier. The transmission was measured with an SNM-5 boron counter or three SNM-37 helium counters.

Calculated corrections for the resolution, the energy dependence of the flux detector efficiency and the multiple scattering of neutrons in the sample were made to the experimental results obtained. The magnitude of the correction for multiple processes in the fissionable sample was calculated by the Monte Carlo method; in the 0.025 eV energy region it was about 2.5%, increasing to 3.5% in the 1 eV region. The correction for resolution was about 2% in the 0.2 eV region in relation to the value at E = 0.0253 eV. An inaccurate knowledge of this correction introduced a systematic error of the order of 0.5% almost comparable to the statistical error of measurement of ~ 0.7%.

Table 1 gives the energy dependence obtained for η of ^{233}U with flux measurements using an (n,γ)-detector with cadmium and indium samples. The energy dependence of the total cross-section for ^{233}U, together with the absolute error, is given in Table 2. Table 3 shows the energy dependence of the ^{233}U fission cross-section with flux measurement by (n,γ)-detectors with cadmium and indium samples. Table 4 contains the recommended values of η and the fission cross-section of ^{233}U in the energy range 0.02–3 eV, obtained by averaging the measured values, which corresponds to a deterioration of resolution by a factor of about 2. The values of η from 1 eV to 3 eV are taken from our 1964 experiments, which showed that in this region η is independent of changes in resolution from 3 to 6 μs/m. The energy dependence of the fission cross-section was obtained under the assumption that ν = const in the neutron energy range studied; it is normalized to a value σ_f = 525.1 b at E = 0.0253 eV.

Table 1

Values of η for ^{233}U (the incident neutron flux was measured using an (n,γ) detector and indium and cadmium samples)

E, eV	Flux for In		Flux for Cd	
	η	$\pm\Delta\eta$	η	$\pm\Delta\eta$
1,0672	2,244	0,037		
0,8968	2,310	0,029		
0,7641	2,332	0,030		
0,6588	2,277	0,032		
0,5739	2,308	0,032		
0,5044	2,325	0,029		
0,4468	2,372	0,036		
0,3985	2,323	0,028		
0,3577	2,326	0,031	2,372	0,027
0,3228	2,357	0,030	2,347	0,029
0,2928	2,322	0,029	2,355	0,029
0,2668	2,253	0,031	2,300	0,027
0,2441	2,240	0,030	2,269	0,025
0,2242	2,149	0,030	2,257	0,029

Continuation of Table 1

E, eV	Flux for In		Flux for Cd	
	η	$\pm\Delta\eta$	η	$\pm\Delta\eta$
0,2066	2,252	0,030	2,242	0,024
0,1910	2,219	0,025	2,215	0,026
0,1771	2,234	0,024	2,216	0,027
0,1647	2,206	0,027	2,185	0,024
0,1535	2,206	0,026	2,183	0,024
0,1434	2,215	0,026	2,175	0,023
0,1343	2,248	0,024	2,213	0,023
0,1261	2,240	0,023	2,230	0,023
0,1185	2,243	0,022	2,219	0,022
0,1117	2,239	0,022	2,243	0,022
0,1054	2,228	0,022	2,230	0,022
0,0996	2,256	0,025	2,235	0,021
0,0943	2,276	0,022	2,263	0,022
0,0894	2,283	0,023	2,275	0,022
0,0849	2,276	0,022	2,285	0,022
0,0807	2,262	0,023	2,256	0,022
0,0768	2,267	0,022	2,267	0,021
0,0732	2,272	0,022	2,285	0,022
0,0698	2,302	0,022	2,300	0,022
0,0667	2,287	0,022	2,294	0,021
0,0637	2,289	0,022	2,304	0,022
0,0610	2,281	0,022	2,290	0,022
0,0584	2,272	0,021	2,294	0,020
0,0560	2,290	0,022	2,288	0,021
0,0537	2,301	0,022	2,302	0,022
0,0516	2,285	0,024	2,303	0,022
0,0496	2,291	0,020	2,298	0,020
0,0477	2,294	0,022	2,304	0,010
0,0459	2,306	0,023	2,308	0,022
0,0442	2,311	0,021	2,305	0,021
0,0427	2,305	0,021	2,308	0,021
0,0411	2,292	0,021	2,299	0,021
0,0397	2,290	0,048	2,294	0,020
0,0383	2,296	0,021	2,310	0,020
0,0371	2,287	0,021	2,308	0,019
0,0358	2,302	0,020	2,306	0,020
0,0347	2,312	0,010	2,306	0,020
0,0335	2,306	0,020	2,299	0,020
0,0325	2,290	0,020	2,295	0,020
0,0315	2,285	0,020	2,286	0,020
0,0305	2,307	0,021	2,295	0,019
0,0296	2,292	0,021	2,316	0,021
0,0287	2,295	0,019	2,303	0,020
0,0279	2,300	0,021	2,288	0,020
0,0271	2,308	0,023	2,298	0,028
0,0263	2,293	0,021	2,302	0,021
0,0256	2,323	0,022	2,301	0,020
0,0249	2,290	0,020	2,300	0,019
0,0242	2,308	0,021	2,307	0,020
0,0235	2,304	0,021	2,293	0,020
0,0229	2,310	0,021	2,315	0,020
0,0223	2,305	0,021	2,282	0,019
0,0217	2,304	0,023	2,297	0,020
0,0212	2,279	0,023	2,288	0,020
0,0207	2,290	0,023	2,289	0,025
0,0201	2,285	0,022	2,292	0,029

Table 2

Total cross-section of ^{233}U

E, eV	σ_t, b	$\pm\Delta\sigma_t$, b	E, eV	σ_t, b	$\pm\Delta\sigma_t$, b
I,0672	I94,96	3,85	0,0610	382,84	I,9I
0,8968	I6I,60	3,66	0,0584	389,09	I,96
0,764I	I50,I5	2,I3	0,0560	396,62	I,88
0,6586	I55,57	2,25	0,0537	403,4I	2,48
0,5739	I60,42	2,98	0,05I6	4I2,46	2,0I
0,5044	I65,73	4,20	0,0496	420,67	2,02
0,4468	I69,93	2,84	0,0477	429,42	2,2I
0,3985	I78,9I	2,20	0,0459	435,77	2,45
0,3577	I84,58	I,54	0,0442	446,33	2,I0
0,3226	I90,72	I,25	0,0427	453,8I	2,I6
0,2928	I97,67	I,67	0,04II	462,I0	2,42
0,2666	209,5I	I,63	0,0397	468,67	2,6I
0,244I	2I7,46	3,55	0,0383	477,93	2,55
0,2242	224,00	I,35	0,037I	485,49	3,05
0,2066	230,7I	2,98	0,0358	492,I2	2,29
0,I9I0	236,04	2,35	0,0347	502,7I	2,73
0,I77I	238,54	I,20	0,03335	5I0,63	2,48
0,I647	246,76	I,40	0,0325	52I,23	2,65
0,I535	250,79	I,53	0,03I5	526,I2	3,0I
0,I434	258,60	I,30	0,0305	537,03	2,57
0,I343	260,I3	I,72	0,0296	543,73	2,72
0,I26I	268,58	I,63	0,0287	55I,69	3,07
0,II85	277,96	I,32	0,0279	559,00	2,59
0,III7	283,82	I,7I	0,027I	570,27	2,95
0,I054	293,47	2,I7	0,0263	58I,45	4,66
0,0996	30I,44	I,87	0,0256	58I,I3	3,00
0,0943	309,7I	I,85	0,0249	594,77	3,I5
0,0894	3I5,67	I,90	0,0242	595,98	3,43
0,0849	323,75	I,9I	0,0235	6I0,78	3,86
0,0807	335,56	2,95	0,0229	6I3,92	3,52
0,0768	340,77	I,7I	0,0223	628,I9	3,08
0,0732	350,22	I,63	0,02I7	63I,74	3,03
0,0698	354,37	I,85	0,02I2	640,02	3,28
0,0667	364,32	2,3I	0,0207	645,42	3,53
0,0637	372,36	2,00	0,020I	657,56	3,6I
0,0I96	665,82	3,63	0,0I24	839,50	7,40
0,0I92	669,43	3,55	0,0I22	843,I4	6,63
0,0I87	682,I3	3,92	0,0II9	849,66	4,I5
0,0I83	69I,74	4,34	0,0II7	858,I5	5,00
0,0I78	702,69	4,50	0,0II5	865,24	4,62
0,0I74	703,59	3,70	0,0II2	875,38	8,00
0,0I70	707,9I	3,27	0,0II0	876,40	6,05
0,0I66	72I,93	3,5I	0,0I08	884,65	6,88
0,0I63	732,52	4,05	0,0I06	899,63	5,36
0,0I59	740,53	5,62	0,0I04	9I5,45	7,I0
0,0I55	74I,56	5,57	0,0I02	9I4,22	8,2I
0,0I52	753,42	6,8I	0,0I0I	93I,45	II,22
0,0I49	763,50	4,24	0,0099	943,46	6,I2
0,0I46	760,77	3,62	0,0097	936,92	9,06
0,0I43	776,54	6,08	0,0095	937,53	II,68
0,0I40	794,48	4,23	0,0094	952,74	8,I7
0,0I37	798,42	4,65	0,0092	979,67	I0,54
0,0I34	806,23	5,24	0,009I	977,07	6,60
0,0I3I	8II,00	4,68	0,0089	992,29	I2,25
0,0I29	822,75	9,08	0,0088	989,98	8,27
0,0I26	825,04	6,00	0,0086	I0I2,22	7,65

Table 3

Fission cross-section of ^{233}U (incident neutron flux measured using (n, γ) detector with indium and cadmium samples)

E, eV	Flux for In		Flux for Cd	
	σ_f, b	$\pm \sigma_f$, b	σ_f, b	$\pm \sigma_f$, b
1,0672	164	4,0		
0,8968	138	3,3		
0,7641	128	2,1		
0,6528	130	2,3		
0,5739	136	2,8		
0,5044	142	3,8		
0,4408	149	3,1		
0,3965	154	2,2		
0,3577	159	2,0	157	1,7
0,3228	167	1,9	166	1,8
0,2828	170	2,1	173	2,1
0,2568	176	2,3	180	2,0
0,2441	182	3,5	184	3,3
0,2242	188	2,3	189	2,3
0,2066	195	3,3	194	2,9
0,1910	197	2,5	196	2,6
0,1771	200	1,8	199	2,2
0,1647	206	2,3	204	2,0
0,1535	210	2,4	207	2,2
0,1434	217	2,4	213	2,0
0,1343	222	2,3	220	2,2
0,1261	229	2,3	228	2,3
0,1165	237	2,0	234	2,0
0,1117	242	2,4	242	2,3
0,1054	249	2,7	250	2,6
0,0996	260	2,9	257	2,4
0,0943	269	2,6	268	2,6
0,0894	276	2,8	275	2,6
0,0849	282	2,7	283	2,7
0,0807	291	4,1	290	3,0
0,0768	296	2,8	296	2,6
0,0732	306	2,7	307	2,7
0,0698	314	2,9	314	2,9
0,0667	321	3,2	321	3,0
0,0637	328	3,1	330	3,2
0,0610	336	3,1	338	3,1
0,0584	341	3,2	344	3,1
0,0560	350	3,2	350	3,0
0,0537	358	3,5	358	3,5
0,0516	364	3,7	367	3,3

Contimuation of Table 3

E, eV	Flux for In		Flux for Cd	
	σ_f, b	$\pm\sigma_f$, b	σ_f, b	$\pm\sigma_f$, b
0,0496	372	3,I	374	3,2
0,0477	38I	3,7	382	4,0
0,0459	388	3,9	389	3,8
0,0442	399	3,5	398	3,5
0,0427	404	3,6	405	3,5
0,04II	409	3,8	4II	3,6
0,0397	4I5	4,0	4I5	3,8
0,0383	424	3,8	426	3,6
0,037I	430	4,2	434	3,9
0,0358	439	3,7	439	3,4
0,0347	450	3,8	449	3,9
0,0335	456	3,6	455	3,9
0,0325	463	4,I	464	4,I
0,0315	466	4,2	466	4,2
0,0305	480	4,3	478	3,9
0,0296	484	4,4	488	4,3
0,0287	492	4,3	493	4,4
0,0279	499	4,4	499	4,2
0,027I	5II	5,I	509	6,3
0,0263	5I8	5,7	5I8	5,7
0,0256	525	5,I	522	4,4
0,0249	530	4,6	53I	4,5
0,0242	534	5,I	534	4,8
0,0235	547	5,4	544	5,2
0,0229	552	5,2	552	5,0
0,0223	563	5,I	557	4,6
0,02I7	566	5,6	564	4,7
0,02I2	567	5,7	569	4,9
0,0207	575	6,0	575	6,5
0,020I	584	5,8	586	7,6

Table 4

Recommended values of η and σ_f for ^{233}U in the energy range 3–0.2 eV

E, eV	η	$\pm\Delta\eta$	σ_f, b	$\pm\Delta\sigma_f$, b	Remarks
2,76	I,64	0,04			
2,II	I,7I	0,04			
I,67	2,08	0,05			
I,35	2,I4	0,06			
I,I2	2,25	0,07			
0,764	2,293	0,02	139	I,0	
0,399	2,34I	0,02	I54	I,0	
0,293	2,328	0,02	I7I	I,0	
0,244	2,284	0,02	I82	I,0	
0,207	2,240	0,02	I92	I,0	
0,I9I	2,223	0,02	I97	I,0	
0,I65	2,20I	0,02	205	I,0	
0.II9	2,229	0,02	235	I,0	
0,0894	2,263	0,02	275	I,0	
0,0690	2,290	0,02	3I4	I,0	
0,056I	2,296	0,02	349	I,5	Normalization region, mean values:
0,0460	2,304	0,02	389	2,0	η = 2,297
0,0384	2,304	0,02	424	2,0	σ_f = 525,I
0,0325	2,295	0,02	463	2,0	
0,0279	2,30I	0,02	50I	2,0	
0,0242	2,302	0,02	537	2,0	
0,0212	2,290	0,02	57I	2,0	

VI. Byelorussian SSR Academy of Sciences
Institute of Nuclear Power Engineering

EVALUATION OF NUCLEAR DATA FOR ^{235}U IN THE NEUTRON ENERGY RANGE 10^{-4}–1 eV

V.A. Kon'shin, N.U. Davydovskaya, E.Sh. Sukhovitskij

Paper submitted to the journal "Vestsi Akademii Navuk BSSR, Seryya Fizika-Ehnergetychnykh Navuk"

Data on σ_a, σ_f, α and η for ^{235}U were evaluated for the neutron energy range 10^{-4}–1 eV on the basis of analysis of experiments conducted by various authors. The "best" curves for $\sigma_a(E)$ and $\sigma_f(E)$ were plotted, and $\eta(E)$ curves measured directly and obtained from the ratio of σ_f to σ_a and from α were compared.

EVALUATION OF NUCLEAR DATA FOR ^{235}U IN THE FORBIDDEN RESONANCE REGION

G.V. Antsipov, E.Sh. Sukhovitskij, V.A. Kon'shin

Paper submitted to the journal "Izvestiya Akad. Nauk BSSR,
Seriya fiziko-ehnergeticheskikh nauk"

The average ^{235}U resonance parameters in the forbidden resonance range of energies (0.15-100 keV) were obtained both by averaging the parameters in the forbidden resonance range ($<\Gamma_\gamma>$ and $<D>_\tau$) and by fitting to the experimental cross-section data. In order to take into account the structure of the cross-sections σ_t and σ_f, the parameters $<\Gamma_n>_3$ and $<\Gamma_n>_4$ were fitted to the mean cross-sections $<\sigma_t>$ for the energy range chosen, while $<\Gamma_f>_4$ was fitted to the cross-sections $<\sigma_f>$. In obtaining $<\Gamma_f>_s$ the competition of neutron inelastic scattering was taken into account. In the calculations of the cross-sections the force function S_1 was taken to be constant, and S_o was determined by fitting to the experimental values of σ_t. With the parameters obtained it was possible to describe fairly well all the experimental data on σ_t, σ_f and α. The calculation with the values $<\Gamma_n>_\tau^\ell$ obtained without fitting of the force function S_o to the data on σ_t showed that in the region below 10 keV no satisfactory description of the experimental data on α is achieved if the fluctuations in σ_t are not taken into account.

EVALUATION OF NUCLEAR CONSTANTS FOR ^{235}U IN THE NEUTRON ENERGY RANGE 10^{-4} eV-15 MeV

V.A. Kon'shin, G.V. Antsipov, G.B. Morogovskij, E.Sh. Sukhovitskij,
A.R. Benderskij, N.U. Davydovskaya

Paper submitted to the scientific and technical publication
"Yadernye konstanty" (Nuclear constants)

The authors briefly describe the results of evaluating the complete file of constants for ^{235}U in the neutron energy range 10^{-4} eV-15 MeV. For the evaluation a detailed analysis was made of all available experimental data for ^{235}U, and a number of methods of evaluating constants was developed and applied for ^{235}U, including: obtaining of self-consistent resonance parameters of the Adler parameter type, obtaining of average statistical parameters of the nucleus in the forbidden resonance region of energies (0.15-100 keV), by means of which it was possible to calculate the average cross-sections in this region (σ_f, σ_t, α), analysis of the angular distributions of elastically scattered neutrons using expansion in the Bessel and Legendre functions, calculation of spectra of γ-rays emitted by ^{235}U on capture, fission and inelastic scattering of neutrons, and calculation of inelastic scattering cross-sections taking into account the competition of fission. The evaluated ^{235}U data were transmitted to the Obninsk Nuclear Data Centre in the SOKRATOR format.

ANALYSIS OF NEUTRON INELASTIC SCATTERING ON THE ^{235}U NUCLEUS

V.I. Martynyuk, G.V. Antsipov, V.P. Korennoj, V.A. Kon'shin

Paper submitted to "Izvestiya Akad. Nauk BSSR,
Seriya fiziko-ehnergeticheskikh nauk"

The authors calculated the cross-sections for neutron inelastic scattering by the ^{235}U nucleus involving excitation of both discrete and continuous level spectra in the energy range up to 3.5 MeV. The calculations took into account effects of competition from the radiative neutron capture and fission reactions and, in the region of allowed levels, the effect of width fluctuation. The calculations were performed for 19 levels of the target nucleus. The results agree closely with the experimental data in the energy region in question, unlike those of the British and German nuclear data libraries.

EVALUATION OF THE NEUTRON INELASTIC SCATTERING CROSS-SECTION FOR ^{235}U

G.V. Antsipov, V.A. Kon'shin, V.P. Korennoj

Presented at the Third Conference on Neutron Physics (Kiev, June 1975)

Using the Hauser-Feschbach formalism taking into account the fluctuations in neutron and fission widths the authors calculated the neutron inelastic scattering cross-sections in the region of allowed and overlapping levels of the target nucleus (0-3.5 MeV). In this calculation the competition of capture and fission was taken into account, as was that of inelastic scattering accompanied by excitation of a continuous spectrum in the calculation of the excitation cross-sections of the various levels. The calculations were performed for 19 levels (415 keV). On the basis of the theoretical calculations and analysis of the direct and indirect experimental information on σ_n' the neutron inelastic scattering cross-sections for ^{235}U were evaluated in the energy range up to 15 MeV.

EVALUATION OF THE NEUTRON INELASTIC SCATTERING CROSS-SECTIONS FOR ^{235}U

G.V. Antsipov, V.A. Kon'shin, V.P. Korennoj, E.Sh. Sukhovitskij

Paper submitted to the scientific and technical publication
"Yadernye konstanty" (Nuclear constants)

The authors evaluated the cross-sections σ_n' for ^{235}U in the range from threshold to 15 MeV. The original data for the evaluation were the results of calculations in the energy range up to 3.5 MeV, experimental data on σ_n' and also indirect experimental information. The evaluated data obtained are compared with the experimental results and the data of the British and German nuclear data libraries. Agreement with experiment was found over the entire energy range. In the region below 1.5 MeV there is a discrepancy between the results of the present work and the data of the other libraries, which are significantly lower than the experimental values. The paper gives the numerical values of the evaluated data.

RESONANCE PARAMETERS OF ^{235}U IN THE ENERGY RANGE UP TO 140 eV

V.A. Kon'shin, G.B. Morogovskij, E.Sh. Sukhovitskij

Presented at Third Conference on Neutron Physics (Kiev, June 1975)

In order to obtain the resonance parameters we analysed the available experimental data on fission and capture cross-sections and the total cross-section of ^{235}U in the energy range up to 140 eV. The presence of powerful interference between the levels due to their proximity, the existence of four fission channels and the asymmetry of the individual resonances made it necessary to use an Adler-Adler-type formalism.

From the experimental data which, it seems to us, contain no significant errors, we obtained Adler-type parameters for the independent description of each type of cross-section, and also self-consistent parameters with which the data on σ_t, σ_f and σ_c can be simultaneously described. The Breit-Wigner parameters were also obtained for consistent description of the cross-sections σ_t, σ_f and σ_c. The cross-sections reconstructed from the multilevel parameters faithfully reproduce the behaviour of $\sigma_i(E)$ over the entire energy range considered. The mean statistical parameters $\langle D \rangle$, $\langle \Gamma_\gamma \rangle$ and $\langle \Gamma_f \rangle$ were determined.

EVALUATION OF THE ANGULAR DISTRIBUTIONS OF NEUTRONS ELASTICALLY SCATTERED ON ^{235}U

E.Sh. Sukhovitskij, A.R. Benderskij, V.A. Kon'shin

Paper submitted to the journal "Izvestiya Akad. Nauk BSSR, Seriya fiziko-ehnergeticheskikh nauk"

The paper presents an analysis of experimental data on the angular distributions of elastically scattered neutrons for ^{235}U in the neutron energy range 0.05-15 MeV. The results are given in the form of a Legendre polynomial expansion. This expansion was obtained using the representation of angular distributions by Bessel function expansion. It was shown that by using Bessel functions certain disadvantages of expansion in Legendre polynomials can be avoided - the negative cross-sections, the large number of expansion factors, and the need for experimental data for the angles 0° and 180°.

EVALUATION OF THE NUCLEAR REACTION CROSS-SECTIONS FOR ^{239}Pu IN THE RESONANCE RANGE OF ENERGIES DURING THE PREPARATION OF A COMPLETE FILE OF CONSTANTS

V.A. Kon'shin, G.B. Morogovskij, E.Sh. Sukhovitskij

Paper published in "Vestsi Akad. Navuk BSSR,
Seriya fizika-ehnergetychnykh navuk"

The authors analysed the available experimental data on σ_f, σ_t and σ_c in order to determine the resonance parameters of ^{239}Pu. The resonance parameters obtained by simultaneous fitting are given in the paper. Comparison of the mean cross-sections with experimental data shows satisfactory agreement between them. The mean values of the resonance parameters are given in the paper.

NUCLEAR DATA FOR ^{239}Pu IN THE FORBIDDEN RESONANCE REGION OF NEUTRON ENERGIES

G.V. Antsipov, A.R. Benderskij, V.A. Kon'shin, E.Sh. Sukhovitskij

Paper submitted to "Izvestiya Akad. Nauk BSSR,
Seriya fiziko-ehnergeticheshykh nauk"

The authors obtained the mean resonance parameters for ^{239}Pu in the energy range 0.3-30 keV. The data were obtained from parameters in the allowed resonance region and also by fitting to evaluated data on the total interaction cross-section σ_t and the fission cross-section σ_f. The quality criterion for the results obtained is comparison of the calculated values of α with the experimental values. With the mean resonance parameters obtained it is possible to calculate α with satisfactory accuracy. Some discrepancy is observed in the region above 10 keV, perhaps because the neutron inelastic scattering reaction was not taken into account.

ANALYSIS OF NEUTRON INELASTIC SCATTERING ON ^{239}Pu

G.V. Antsipov, V.P. Korennoj, V.I. Martynyuk

Presented at Third Conference on Neutron Physics
(Kiev, June 1975)

Using the framework of the statistical model, σ'_n on the ^{239}Pu nucleus was calculated for the neutron energy range E = 0.1-4 MeV, taking into account the competition from the (n,γ) and (n,f) reactions and the width fluctuation effect. At energy $E_n > 0.5$ MeV the contribution of the continuous spectrum was taken into consideration. The fission widths were evaluated up to an energy of 0.5 MeV on the basis of the channel theory of fission, and at higher energies in an approximation of independence of τ. The calculation results were compared with experimental data and existing values for σ'_n and σ'^{Ej}_n.

EVALUATION OF THE CROSS-SECTIONS OF THE (n,2n) AND (n,3n) REACTIONS FOR ^{239}Pu

E.Sh. Sukhovitskij, V.A. Kon'shin

Paper submitted to "Izvestiya Akad. Nauk BSSR,
Seriya fiziko-ehnergeticheskikh nauk"

The authors propose a model for calculating the cross-sections of the (n,2n) and (n,3n) reactions. Experimental data on the interaction of neutrons with nuclei were used in constructing the model. The cross-sections of the (n,2n) and (n,3n) reactions for ^{235}Pu and ^{238}U are given, and the results of this work are compared with other evaluations.

EVALUATION OF THE NEUTRON CROSS-SECTIONS OF ^{240}Pu IN THE FORBIDDEN RESONANCE REGION

G.V. Antsipov, A.R. Benderskij, V.A. Kon'shin, E.Sh. Sukhovitskij

Presented at Third Conference on Neutron Physics
(Kiev, June 1975)

On the basis of the available experimental data the mean resonance parameters were evaluated taking into account the competition of inelastic scattering.

In the evaluation the concept of a double-humped structure of the fission barrier was used, which made it possible correctly to evaluate the fission penetration and width fluctuation factors. The evaluated parameters of the two-humped fission barrier are given. With the mean resonance parameters obtained it is possible to calculate the cross-sections σ_t, $\sigma_{n\gamma}$, σ_f, $\sigma_{nn'}$ and their errors in the energy range 1-100 keV. This paper is part of the work on compilation of a complete file of constants for ^{240}Pu.

EVALUATION OF THE NUCLEAR CONSTANTS OF ^{240}Pu FOR COMPILING A COMPLETE FILE

G.V. Antsipov, A.R. Benderskij, V.A. Kon'shin, E.Sh. Sukhovitskij

Sent to Third Conference on Neutron Physics
(Kiev, June 1975)

The paper contains a compilation of all available experimental data on ^{240}Pu. On the basis of this compilation the neutron cross-sections are evaluated for the range 10^{-4} eV-15 MeV using the concept of a double-humped fission barrier structure. The cross-sections in the resonance region are described by resonance parameters.

For the forbidden resonance region the mean resonance parameters are given as functions of energy. In evaluating the cross-sections and angular distributions in the high-energy region, where experimental data are lacking, the statistical model of the nucleus and the connected channel model are used. The spectra of neutrons and gamma rays from inelastic processes are evaluated. The cross-sections are presented in the usual format.

NUCLEAR PHYSICS CONSTANTS FOR TRANSPLUTONIUM ELEMENTS

V.A. Kon'shin

Paper published in "Izvestiya Akad. Nauk BSSR, Seriya fiziko-ehnergeticheskikh nauk"

The paper contains evaluated nuclear data for transplutonium elements at thermal energies. The available experimental data on $\bar{\nu}$, σ_f^{2200}, σ_c^{2200}, I_f and I_c for ^{247}Cm, ^{249}Cf and ^{251}Cf are surveyed and analysed. A table gives nuclear data for the chain of formation of the elements from ^{239}Pu to ^{257}Fm.

CALCULATION OF THE ACCUMULATION OF TRANSPLUTONIUM ELEMENTS IN THERMAL AND RESONANCE NEUTRON FLUXES

G.V. Antsipov, V.A. Kon'shin, G.A. Sarnadskij

Presented at Third Conference on Neutron Physics (Kiev, June 1975)

The accumulation of transplutonium elements in thermal and resonance neutron fluxes was calculated. The dependence of the yields of these elements on the relation of the thermal flux to the epithermal flux in a constant full flux and on the neutron temperature was studied. The influence of errors in the experimental data for σ_f, σ_c, I_γ and I_c on the values for transuranium element accumulation was studied.

EVALUATION OF $\alpha(^{235}U)$ IN THE ENERGY RANGE 0.1 keV–15 MeV

G.V. Antsipov, V.A. Kon'shin

Presented at Third Conference on Neutron Physics (Kiev, June 1975)

The available experimental data on $\alpha(^{235}U)$ in the energy range above 100 eV were analysed from the point of view of possible systematic errors affecting six aspects: standardization, σ_f comparison, function of gamma-ray and fission detectors, background determination and energy resolution.

Using the mean statistical parameters evaluated by us we calculated the value of α. The influence of fluctuation in the force function S_o and of change in $< \Gamma_\gamma >$ on the results of the calculation of α was studied.