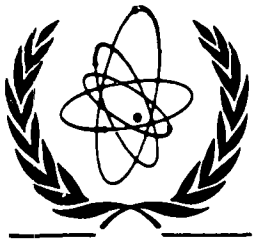
INDC(CCP)-100/U



International Atomic Energy Agency

INDC INTERNATIONAL NUCLEAR DATA COMMITTEE

USSR State Committee on the Utilization

of Atomic Energy

NUCLEAR PHYSICS RESEARCH IN THE USSR

Collected Abstracts

Issue 22

Translated by the IAEA
February 1977

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

Reproduced by the IAEA in Austria
March 1977
77-1977

INDC(CCP)-100/U

USSR State Committee on the Utilization

of Atomic Energy

NUCLEAR PHYSICS RESEARCH IN THE USSR

Collected Abstracts

Issue 22

Translated by the IAEA

February 1977

CONTENTS

Institute of Physics and Power Engineering

INVESTIGATION OF LOW-ENERGY DELAYED NEUTRONS FROM SPONTANEOUS FISSION OF ^{252}Cf

V.M. Piksajkin, P.P. D'yachenko, A. Lajtai, N.N. Semenova, E.A. Seregina, L.S. Kutsaeva

The authors investigated the emission of delayed neutrons during spontaneous fission of ^{252}Cf in the energy range $E_n < 1$ MeV using a method similar to that employed in Ref. [1]. The neutron detector used was NE-908 lithium glass which separates neutrons and gamma rays [2]. The measurements were performed for two angles between the line of fragment divergence and the direction of neutron escape - 90° and 0° respectively. The results are given in the table. The following conclusion was drawn on the basis of the results obtained: if delayed neutrons are emitted during spontaneous fission of ^{252}Cf in a time span $5 \times 10^{-10} < t < 1.5 \times 10^{-6}$ sec and in the energy range 10 keV $< E_n <$ 1 MeV (they are emitted isotropically in the co-ordinate system of a moving fragment), their yield does not exceed 0.1% of the total number of neutrons emitted per fission event.

Table

Geometry	90°		0°	
Number of foils	1	2	1	2
Expected value of A (%)	1.3	1.3	-10	-10
Measured value of A (%)	0.66 + 0.33	1.73 + 0.67	0.28 + 1.21	-1.49 + 1.15

REFERENCES

[1] DYACHENKO, P.P., PIKSAJKIN, V.M., LAJTAI, A., Preprint KFKI-45, 1973.

[2] LAJTAI, A., KLUGE, D. et al., Proc. 3rd All-Union Neutron Physics Conf. Kiev, 1975.

EVALUATED MEAN ^{238}U RADIATIVE CAPTURE CROSS-SECTIONS IN THE 0.001-7 MeV ENERGY RANGE

V.N. Vinogradov, A.N. Davletshin, A.S. Krivtsov,
N.S. Rabotnov, V.A. Tolstikov, V.S. Shorin

Evaluated mean cross-sections for the radiative capture of neutrons in the 0.001-7 MeV energy range by ^{238}U nuclei are presented.

In the 0.001-0.1 MeV energy range the experimental data were evaluated on the basis of the mean model parameters of the statistical theory of nuclear reactions [1]. Experimental data from Refs [3-10] were used in the evaluation.

For energies $E_n > 0.1$ MeV the mean curve for $\sigma_{n\gamma}(E)$ was constructed by the rational approximation method in the Padé approximation [2]. For this purpose all the experimental data of the different authors were treated as a single statistical ensemble. The experimental data of the different authors were first averaged so that the averaging intervals contained the same number of experimental "points" for each author. The experimental data from Refs [11-17] were also used in this energy range. The experimental data of Refs [10, 12-14, 17] were normalized at 30 keV to 454 ± 18 mb. The results of evaluation by the rational approximation method and the statistical theory method agree to within 1-2%.

The results of the evaluation are presented in Table 1. Table 2 compares the ^{238}U group capture cross-sections according to the BNAB-70 [18] and OSKAR-75 [19] evaluations, the group capture cross-sections compiled by us from the evaluations of Sowerby [20, 21] and the results of our present evaluation. When calculating the group constants for groups 4-26 averaging was performed over the 1/E spectrum, and for the remaining groups over the standard fission spectrum [22].

Table 1

Evaluated ^{238}U capture cross-sections

E_n, MeV	$\sigma_{n\gamma}$ barn	E_n, MeV	$\sigma_{n\gamma}$ barn	E_n, MeV	$\sigma_{n\gamma}$ barn	E_n, MeV	$\sigma_{n\gamma}$ barn
0,0015	1,985	0,055	0,328	0,360	0,115	1,000	0,123
0,00247	1,415	0,0633	0,291	0,391	0,1135	1,026	0,121
0,0035	1,140	0,065	0,284	0,400	0,113	1,100	0,113
0,0045	0,990	0,0712	0,262	0,420	0,1125	1,200	0,101
0,0055	0,892	0,075	0,225	0,453	0,112	1,300	0,0895
0,0065	0,822	0,105	0,189	0,485	0,1125	1,500	0,0694
0,0075	0,770	0,110	0,186	0,500	0,113	1,800	0,0496
0,0085	0,730	0,125	0,176	0,544	0,1145	2,000	0,0411
0,0095	0,697	0,130	0,173	0,600	0,1175	2,200	0,0348
0,0145	0,591	0,145	0,165	0,624	0,119	2,500	0,0262
0,015	0,583	0,150	0,163	0,642	0,120	2,800	0,0235
0,0242	0,488	0,180	0,150	0,682	0,123	3,000	0,0211
0,025	0,482	0,200	0,143	0,700	0,124	3,500	0,0167
0,0346	0,428	0,220	0,137	0,752	0,127	4,00	0,0130
0,035	0,426	0,250	0,130	0,800	0,129	5,00	0,010
0,0438	0,393	0,280	0,124	0,840	0,1295	6,00	0,0077
0,045	0,384	0,300	0,121	0,850	0,1295	7,00	0,0061
0,050	0,354	0,320	0,119	0,900	0,129		

Table 2

Comparison of group constants of ^{238}U capture cross-sections

Number of group	Energy range (MeV)	BNAB-70 (mb) [18]	OSKAR-75 (mb) [19]	According to Sowerby-I (mb) [20]	According to Sowerby-II (mb) [21]	According to authors own data (mb)	$\frac{\sigma_7-\sigma_3}{\sigma_7}$ %	$\frac{\sigma_7-\sigma_4}{\sigma_7}$ %	$\frac{\sigma_7-\sigma_5}{\sigma_7}$ %	$\frac{\sigma_7-\sigma_6}{\sigma_7}$ %
1	6.5 ÷ 4	12	10	10,7	8,4	10,7	-10,5	+6,5	0	+ 21,5
2	4 ÷ 2,5	24	23	25,2	20	20,6	-16,5	-11,9	-22,3	+ 2,3
3	2,5 ÷ 1,4	60	62	66,6	52	49,1	-18,1	-22,2	-35,5	- 5,8
4	1,4 ÷ 0,8	130	127	137,8	116	112,6	-15,4	-12,8	-22,3	- 3
5	0,8 ÷ 0,4	130	119	131,7	116	117,7	-10,4	- 1,1	-11,9	+ 1,4
6	0,4 ÷ 0,2	140	121	134,4	125	125,4	-11,6	+ 3,5	- 7,2	+ 0,3
7	0.2 ÷ 0,1	180	157	174	167	167,2	- 7,9	+ 6,4	- 3,7	+ 0,4
8	0,1 ÷0.0465	260	249	268	270	278	+ 6,4	+10,4	+ 3,6	+ 2,9
9	0,0465÷0.0215	450	419	451	464	445	- 1,1	+ 5,9	- 1,4	- 4,3
10	0,0215÷0.01	600	618	663	654	597	-10,5	- 3,5	- 11	- 9,5
11	0,01 ÷0,00465	900	797	856	878	814	- 8,3	+ 4,1	- 3	- 5,7
12	0,00465÷0,00215	1300	933	1003	1322	1242	- 4,7	+ 2,5	+19,2	- 6,4

REFERENCES

[1] TOLSTIKOV, V.A., SHORIN, V.S., in Voprosy atomnoj nauki i tekhniki, seriya "Yadernye konstanty" (Questions of atomic science and technology, "Nuclear Constants" series), issue 20, part 2 (1975) 61.

[2] VINOGRADOV, V.N., DAVLETSHIN, A.N., PLATONOV, V.P. et al., Radiatsionnyj zakhvat bystrykh nejtronov yadrom ^{238}U (Radiative capture of fast neutrons by a ^{238}U nucleus), Proc. 3rd Neutron Physics Conf. Kiev, 1975.

[3] Moxon M.C. Report AERE-R-6074,1969. Private Communication from M.C.Moxon to Z.Stewart. September,1971.

[4] Fricke M.P., Zopez W.M.,Friesenhahn,S.J., Carlson A.D., Costello D.G. Nucl.Data for Reactors. Vienna,IAEA,1970, v.2, p.265.

[5] G. De Saussure,Silver E.G., Perez R.B.,Iugle R.,Weaver U. Nucl.Sci.Eng.1973, 51,385.

[6] CHELNOKOV, V.B., TOLSTIKOV, V.A., STAVISSKIJ, Yu.Ya. et al., Institute of Physics and Power Engineering preprint, FEI-292, Obninsk (1971).

[7] TOLSTIKOV, V.A., SHERMAN, L.E., STAVISSKIJ, Yu.Ya., J. Nucl. Energy A/B 18 (1964) 599.

[8] Moulove M.C., Poenitz W.P. Nucl.Sci.Eng.1968, v.33, p.24.

[9] Poenitz W.P. Nucl.Sci.Eng. 1975, v.57, p.300.

[10] PANITKIN, Yu.G., STAVISSKIJ, Yu.Ya., TOLSTIKOV, V.A., in Nuclear Data for Reactors (Proc. Conf. Helsinki, 1970) 2, IAEA, Vienna (1970) 57.

[11] DAVLETSHIN, A.N., TIPUNKOV, A.O., TOLSTIKOV, V.A., Secheniya radiatsionnogo zakhvata nejtronov s ehnergiej 0.6–1 MeV yadrom ^{238}U (Cross-sections for the radiative capture of neutrons in the 0.6–1 MeV energy range by a ^{238}U nucleus) Paper presented at the 3rd Neutron Physics Conf. Kiev, 1975.

[12] PANITKIN, Yu.G., TOLSTIKOV, V.A., STAVISSKIJ, Yu.Ya., Proc. All-Union Neutron Physics Conference, Naukova dumkapress, part 1, Kiev (1972) 321.

[13] PANITKIN, Yu.G., TOLSTIKOV, V.A., At. Ehnerg. 33 (1972) 782.

[14] PANITKIN, Yu.G., TOLSTIKOV, V.A., At. Ehnerg. 33 (1972) 825.

[15] Hanna R.C., Rose B. J.Nucl.Energy,1959,8,157.

[16] Ryves T.B., Hunt J.B.,Robertson J.C. Journ.Nucl. Energy, 1973,27.519.

[17] TOLSTIKOV, V.A., ABRAMOV, A.I., Communication made during the discussions on the work programme at the 2nd meeting of INDC at BNL (1963).

[18] ORLOV, V.V. et al., Institute of Physics and Power Engineering preprint, FEI-306, Obninsk (1972).

[19] BOBKOV, Yu.G. et al., Sravnitel'nyj analiz gruppovykh konstant, poluchennykh na osnove biblioteki UKNDL i sistemy BNAB-70 (Comparative analysis of group constants obtained on the basis of the UKNDL and the BNAB-70 system) Proc. 3rd Neutron Physics Conf. Kiev, 1975.

BOBKOV, Yu.G., DULIN, V.A., KAZANSKIJ, Yu.Ya et al., Podgonka gruppovykh konstant po otsenennym integral'nym ehksperimentam i poslednim versiyam otsenennykh mikroskopicheskikh yadernykh dannykh (Adjustment of group constants on the basis of evaluated integral experiments and the latest evaluated microscopic nuclear data) ibid.

[20] Sowerby M.G., Patrick B.H., Mather D.S. AERE-R-7273.1973.

[21] Sowerby M.G., Patrick B.H., Mather D.C. Annals of Nuclear Science and Engineering,1974, v.1, No.7/8, p.409.

[22] KOLESOV, V.E., KRIVTSOV, A.S., Algoritm i programma podgotovki gruppovikh konstant rascheta reaktorov na osnove biblioteki nejtronnykh dannykh sistemy "SOKRATOR" (Algorithm and programmes for obtaining group constants for reactor calculations on the basis of the SOKRATOR system neutron data library) Proc. 3rd Neutron Physics Conf. Kiev, 1975.

ANALYSIS OF THE SPECTRA OF INELASTICALLY SCATTERED NEUTRONS WITH INITIAL ENERGIES OF 7, 9 AND 14 MeV

V.I. Plyaskin, V.I. Trykova

(Article for publication in "Questions of atomic science and technology", "Nuclear constants" series)

The results of an analysis of the integral spectra of inelastically scattered neutrons with initial energies of 7, 9 and 14 MeV, performed for 8, 6 and 18 nuclei respectively, are presented. The parameters of models giving the best description of the experimental data are obtained.

THE APPLICATION OF A CONTROLLABLE-STRENGTH NEUTRON SOURCE IN EXPERIMENTS ON CRITICAL ASSEMBLIES

O.A. Elovskij, E.S. Matusevich, O.A. Trykov

(Article for publication in "Atomnaya Ehnergiya")

Some applications in reactor experiments of the pulsed-type P_0-α-Be neutron sources which have become available in recent years are considered. To illustrate how such sources can be used for measuring negative reactivity, the authors present the results of reactivity measurements performed by the method of "switching off" the source (stimulation method) up to (4-5) β_{eff} on a fast critical assembly with a beryllium reflector.

Comparison of reactivity measurements by the rod-drop and switching-off methods show, in the case of the latter, only a slight dependence of the measured effect on the position of the detectors around the critical assembly, whereas with the rod-drop method the effect can vary by a factor of more than 2.

Measurements of the spatial distribution of neutron importance performed with the aid of P_0-α-Be and ^{252}Cf sources show a weak dependence of the relative neutron importance in the system investigated on the neutron spectrum of the source. The neutron spectrum of the source for the switched-on and switched-off conditions is presented.

I.V. Kurchatov Institute of Atomic Energy

FAST NEUTRON FISSION CROSS-SECTION OF ^{244}Pu

B.M. Gokhberg, S.M. Dubrovina, V.A. Shigin

Measurements of the neutron-induced fission cross-section of ^{244}Pu in the 0.28–1.8 MeV energy range are presented. The measurements were performed on an electrostatic accelerator. The glass method was used for recording the fission fragments.

The table shows the ^{244}Pu fission cross-sections at different energies and the errors in the relative curve of the fission cross-section.

To absolutize the ^{244}Pu cross-section, a comparison was performed with the fission cross-section of a standard specimen of ^{239}Pu at E_n = 1.03 MeV, taken as 1.77 barn. The absolutization error is approximately 5% and the energy resolution about 40 keV.

Table

Neutron-induced fission cross-section of ^{244}Pu

E_n, keV	σ_f, mb	$\Delta\sigma_f$, mb
280	19	1,5
425	56	3
515	112	5
620	232	10
725	459	20
830	729	20
930	1015	30
1030	1166	30
1230	1117	30
1330	1166	30
1430	1139	30
1530	1096	30
1630	1107	30
1730	1063	30
1825	1069	30

MEASUREMENT OF THE THRESHOLD FOR NEUTRON-INDUCED FISSION OF ^{244}Pu

Eh. F. Fomushkin, B.K. Maslennikov, G.F. Novoselov,
V.M. Surin, G.F. Khodalev

The energy dependence of the ^{244}Pu fission cross-section was investigated in an EhG-5 electrostatic accelerator with the aid of dielectric track detectors. Apart from the basic isotope, the sample investigated also contained ^{242}Pu (1.34 at.% relative to the content of ^{244}Pu), ^{240}Pu (0.305 at.%), ^{238}Pu (≤ 0.126 at.%) as well as negligible amounts of odd isotopes of plutonium and certain other isotopes. The measurements were performed with reference to 90% enriched ^{235}U in the neutron energy range E_n = 0.52 - 2.50 MeV; the results are shown in the table.

Table

E_n, keV	ΔE_n, keV	$\sigma_f^{244}Pu$, barn	$\Delta\sigma_f/\sigma_f$
520	60	0,073	0,032
720	55	0,257	0,109
820	50	0,416	0,074
930	50	0,715	0,020
1030	45	0,804	0,035
1150	45	0,966	0,053
1400	40	1,051	0,037
2000	40	0,987	0,030
2500	40	0,935	0,029

The errors shown in the table are the mean square statistical errors; the systematic error was $\gtrsim$ 10%.

On the basis of these results the authors estimated the parameters of the fission threshold according to the liquid-drop model as follows: neutron energy threshold $E_{thr} = 0.85 \pm 0.015$ MeV and barrier curvature parameter $\hbar\omega = 0.63 \pm 0.05$ MeV.

V.G. Khlopin Radium Institute

ABSOLUTE MEASUREMENTS OF CROSS-SECTIONS FOR THE FISSION OF ^{235}U AND ^{238}U BY 14.8 MeV NEUTRONS

I.D. Alkhazov, O.I. Kostochkin, L.Z. Malkin, K.A. Petrzhak, A.V. Fomichev, V.I. Shpakov

The fission cross-sections of ^{235}U and ^{238}U were measured during irradiation by 14.8 MeV neutrons using the associated particle - fission fragment coincidence method. The neutron source was a neutron generator operating on the basis of the reaction $^{2}H(\alpha,n)^{4}He$. The associated alpha particles were recorded with a thin layer of scintillation plastic and the fission fragments were recorded in the solid angle by a 2π ionization chamber operating in pulsed mode. The coincidences were recorded by means of a coincidence circuit with a resolution time $2\tau = 20$ nsec. In addition, a time analysis of the coincidences was carried out with a time-amplitude converter.

The measurements were corrected for the background of random coincidences, losses in the flux of bombarding neutrons and the efficiency of recording of the fragments. The latter correction consists of two parts: correction for "non-emergence" of fragments from the layer and a correction for the plateau slope of the ionization chamber counting characteristic. The random coincidence background was determined from the time spectrum and also by means of a coincidence circuit with an additional lag. The corrections for losses in the neutron flux were determined experimentally by doubling the thickness of the absorbing and scattering materials, and also by calculation. The plateau slope of the chamber counting characteristic was determined by means of two integral discriminators with different thresholds which were connected simultaneously to the measuring circuit. Corrections for "non-emergence" of fragments from the layer of fissionable material were determined by calculation, taking fission anisotropy into account.

The targets of fissionable material were fabricated by high-frequency evaporation in an argon atmosphere. The uniformity of the layer of material in the target was determined by scanning the surface of the target with an alpha counter and was better than 1%. The targets were weighed according to the alpha activity in the 2π solid angle geometry for ^{238}U and in a small solid angle for ^{235}U, using the half-life values from Ref. [1].

The table shows the errors in all the quantities associated with the determination of the fission cross-section (standard errors).

As a result of the measurements the fission cross-section of ^{235}U was determined as 2.188 ± 0.033 barn and that of ^{238}U as 1.207 ± 0.019 barn.

REFERENCE

[1] JAFFEY, A.H., FLYNN, K.F., GLENDENIN, L.E., BENTLEY, W.G., ESSLING, A.M., Phys. Rev. C4, No. 5 (1971) 1889.

See over for table.

Table of errors associated with the measurement of the fission cross-sections

Sources of errors		Error	
		For ^{235}U	For ^{238}U
Error in weighing the target in a chamber with a small solid angle	Solid angle	0.30	
	Statistical error	0.35	
	Fraction of the isotope under investigation	0.41	
	Half-life	0.20	
Weighing error	Statistical error		0.55
Targets in chamber with 2π geometry	Extrapolation of alpha-particle spectrum to zero energy		0.51
	Correction for absorption in the layer and scattering		0.30
	Fraction of the isotope under investigation		0.10
	Half-life		0.20
Error in determining the number of fissions	Statistical error	1.0	1.0
	Error in number of random coincidences	0.20	0.20
	Error in determining neutron flux losses	0.80	0.80
	Error in determining fragment absorption in the layer	0.30	0.30
	Error in extrapolating the fragment spectrum to zero energy	0.20	0.20
Error in determining the number of associated particles		0.05	0.05
Total error in the determination of the corss-section		1.5	1.6

ABSOLUTE MEASUREMENTS OF CROSS-SECTIONS FOR FISSION OF ^{235}U AND ^{238}U BY NEUTRONS FROM THE ^{252}Cf FISSION SPECTRUM

V.M. Adamov, L.V. Drapchinskij, S.S. Kovalenko, G.Yu. Kudryavtsev, K.A. Petrzhak, L.A. Pleskachevskij, A.M. Sokolov

Absolute measurements were performed of the corss-sections for fission of ^{235}U and ^{238}U by neutrons from the ^{252}Cf fission spectrum. The measurements were performed by a coincidence counting method relying on coincidences of fission fragments in a target of the isotope under investigation produced by fragments from the spontaneous fission of ^{252}Cf.

Source and target were separated because had they been directly adjacent there would have been a large probability of scattering for neutrons passing from the source to the edges of the target. A special assembly was constructed for accurate positioning of the source and target. To reduce the fraction of scattered neutrons, the amount of material used in the assembly was kept to a minimum and the backings on which the isotopes under investigation and the ^{252}Cf source were coated were made only 300-500 μm thick.

The targets of ^{235}U and ^{238}U were prepared by high-frequency evaporation in an argon atmosphere. The uniformity of distribution of the substance over the target was better than 1%.

The fission fragments were recorded with a pulse-type back-to-back ionization chamber. Threefold doubling of the number of fission coincidences in the target and the ^{252}Cf was introduced. A time analysis of the coincidences over a time interval of 100 nsec was performed with a time-amplitude converter. An amplitude analysis of the pulse spectrum of the isotope under investigation was also performed.

The geometrical conditions of the experiment were calculated, taking into account the extended nature of the ^{252}Cf source of fission and the scattering of neutrons by the backing material.

Table 1 shows the errors in all the quantities associated with determination of the fission cross-sections.

Table 2 shows the authors' cross-sections for fission of ^{235}U and ^{238}U by neutrons of the ^{252}Cf fission spectrum, which are in agreement with other data [1]. It also includes calculated integral fission cross-sections based on differential measurements of fission cross-sections [2]. The fission

spectrum was approximated in the calculation by the Maxwellian distribution: $n(E) = \sqrt{E}\, e - E/T$ with the parameter T = 1046 keV.

Table 1

Source of errors		^{235}U (%)	^{238}U (%)
Geometrical factor		0.71	0.71
$\bar{\nu}$ (^{252}Cf)		0.35	0.35
Weighing error in a chamber with small solid angle	Solid angle	0.3	
	Statistical error	0.35	
	Fraction of isotope under investigation	0.41	
	Half-life	0.068	
Weighing error in a chamber with 2π geometry	Statistical error		0.55
	Extrapolation of alpha-particle spectrum to zero energy		0.51
	Correction for absorption in the layer and scattering		0.30
	Fraction of isotope under investigation*/		0.30
Error in determining the number of fissions of the isotope under investigation	Statistical error	0.8	1.11
	Correction for absorption in the layer	0.3	0.25
	Extrapolation of fragment spectrum to zero energy	0.40	0.37
	Error in determining the fission contribution from impurities	0.30	0.14
Error in the determination of the cross-section		1.44	1.68

*/ The error in determining the half-life of ^{238}U is included in the error in determining its fraction.

Table 2

Nucleus	Fission cross-section		
	Obtained by authors	Ref.[1]	Calculation
^{235}U	1266 ± 19	1207 ± 52	1281
^{238}U	347 ± 6	324 ± 14	352

REFERENCES

[1] GRUNDL, I.A. et al., Trans. Am. Nucl. Soc., 15 (1972) 945.

[2] LAIGNER, I. et al., Tables of evaluated neutron cross-sections for fast reactor materials.

X-RADIATION OF FRAGMENTS RESULTING FROM ^{235}U FISSION BY 3.5 MeV NEUTRONS

A.G. Donichkin, A.N. Smirnov, V.P. Ehjsmont

(Article for publication in "Yadernaya Fizika")

The yields and energy spectra of the K-series of characteristic X-rays from a heavy fragment resulting from fission of ^{235}U by 3.5 MeV neutrons and thermal neutrons were measured with a semiconductor spectrometer. The yields of KX-rays for fragments with a fixed charge were determined by computer expansion of the spectra. The ratios of the yields of KX-radiation from fragments resulting from fast fission to the yields of fragments from thermal fission for different charges are given in the table.

Z	51	52	53	54	55	56	57	58	59
$\frac{W_{kx}(3,5)}{W_{kx}(0)}$	1,14 ± 0,17	0,97 ±0,10	0,92 ±0,05	0,83 ±0,06	0,35 ±0,05	0,90 ±0,05	1,18 ±0,12	1,00 ±0,15	1,70 ±0,34

The results indicate the general similarity of the emission characteristics of X-rays produced in the fission of nuclei with different forms of excitation, as well as the considerable thermal stability of the charge distributions.

THE EXCITATION MECHANISM OF MULTIPOLAR RESONANCES IN NUCLEI

Eh.I. Dubovoj

(Article for publication in "Yadernaya Fizika")

The energy positions, spins and parities of multipolar resonances in nuclei excited in inelastic scattering reactions of charged particles are calculated on the basis of the three-stage mechanism for the excitation of resonances in nuclei proposed earlier and compared with measured values. The theory is in agreement with experiment. Multipolar excitations of ^{16}O, ^{40}Ca, ^{208}Pb and ^{28}Si nuclei are considered.

KX-RAY SPECTRA OF FRAGMENTS FROM FAST FISSION OF ^{235}U AND THE ENERGY DEPENDENCE OF $\bar{\nu}$ IN THE HEAT BALANCE METHOD

A.G. Donichkin, A.N. Smirnov, V.P. Ehjsmont

(Article for publication in "Atomnaya Ehnergiya")

Using a semiconductor spectrometer of soft electromagnetic radiation, the authors measured the energy spectra and yields, $W_{kx}(E_n)$, of the K series of X-rays from heavy fragments during the fission of ^{235}U by neutrons with energies of 0.7, 1.2 and 3.5 MeV. The energy spectra and yields, $W_{kx}(0)$, of X-rays produced in thermal fission were measured under similar conditions. The ratio of these yields is shown in Table 1.

Table 1

E_n, MeV	0,7	I,2	3,5
$\frac{W_{kx}(E_n)}{W_{kx}(0)}$	0,97 ± 0,07	0,85 ± 0,0I	I,05 ± 0,I5

The mean charges were determined in three ranges.

Table 2

Charge ranges	Neutron energy (MeV)		
	Thermal	0,7	3,5
5I-53	52,43	52,28	52,38
54-56	54,98	55,07	55,00
57-59	57,53	57,49	57,62

The variation of the mean charges is by and large less than 0.1 charge unit. This means that the upper error limit in the determination of $\bar{\nu}$ by the heat balance method (with no allowance for variation in charges) for neutrons with energies up to 3.5 MeV is around 1.5%. Even-odd fluctuations of fragment charges should be taken into account with an accuracy of about 1%

PROBABILITY OF FISSION BY GAMMA RAYS WITH A MAXIMUM ENERGY OF 1.33 MeV AND THE PERIOD OF SPONTANEOUS FISSION OF ^{238}U

K.N. Ivanov, K.A. Petrzhak

The probability of fission of ^{238}U by gamma rays with a maximum energy of 1.332 MeV was determined. The gamma ray source was a GU-5000 geq ^{60}Co facility. ^{238}U targets were prepared in the form of U_3O_8 tablets 2 mm thick. The fission fragments were recorded with mica track detectors. The effective number of nuclei in the tablets was determined in relative measurements. For this purpose a target of ^{238}U metal foil and U_3O_8 tablet were irradiated simultaneously. Then the number of ^{238}U nuclei in the tablets was determined from the ratios of the fast fission yields (E_n = 14.1 MeV) and the effective number of nuclei in 1 cm^2 of uranium metal [1].

The gamma dose rate was determined with Fricke dosimeters by the standard procedure.

In order to take into account spontaneous fission of ^{238}U nuclei and that induced by cosmic radiation, control targets were set up in the building housing the facility and in the underground 40 m below sea level.

The control targets were left in their respective locations for 255 days. The targets were irradiated with gamma rays for 4582 hours.

The difference in the number of fissions between control and irradiated targets was ascribed to induced fission of ^{238}U. The results of the experiment indicate an upper limit of the cross-section for fission of ^{238}U by gamma rays with a maximum energy of 1.332 MeV equal to $(2.08 \pm 2.1) \times 10^{-13}$ barn.

From the absolute record of the fission fragments obtained with the mica detectors and the number of spontaneous fission events in the control targets the period of spontaneous fission of ^{238}U was determined as $T_{sp.f.} = (9.73 \pm 0.44) \times 10^{15}$ years, which agrees with the value $(9.87 \pm 0.155) \times 10^{15}$ years given in a recent publication [1].

REFERENCE

[1] ROBERTS, I.H., Phys. Rev., 174 (1968) 1482.

Institute of Nuclear Research of the
Academy of Sciences of the Ukrainian SSR

TOTAL CROSS-SECTIONS OF EUROPIUM-152 ($T_{\frac{1}{2}}$ = 12.4 YEARS) IN THE NEUTRON ENERGY RANGE 0.0065-0.17 eV AND OF EUROPIUM-154 AT 0.0253 eV NEUTRON ENERGY

V.F. Razbudej, V.P. Vertebnyj, A.V. Muravitskij

The energy dependence of the total neutron cross-section of a radioactive europium-152 nucleus ($T_{\frac{1}{2}}$ = 12.4 years) was determined by a time-of-flight spectrometer with a thin beam of thermal neutrons in the 0.0065-0.17 eV energy range (resolution 40 μsec/m). The cross-section was determined by measuring the transmission of a sample of europium-151 irradiated with different doses of thermal neutrons up to 2.2×10^{20} n/cm^2 and then analysing the experimental data on the basis of the equations of nuclear transformation kinetics. The results are given in Table 1. At a neutron energy of 0.0253 eV the total cross-section of europium-152 is 11 400 ± 1400 barn.

The Westcott g-factors for europium-152 in the neutron gas temperature range 0-200°C were calculated from the data obtained with an accuracy of 6% (Table 2).

For the isotope europium-154 a total cross-section σ = 1530 ± 200 barn was obtained at a neutron energy of 0.0253 eV. The work was carried out at the Institute of Nuclear Research of the Academy of Sciences of the Ukrainian SSR.

Table 1

Total neutron cross-section of europium-152 ($T_{\frac{1}{2}}$ = 12.4 years)

E, eV	σ, barn	$\pm \Delta\sigma$
0,168	2200	2000
0,103	3690	I400
0,070	4980	II00
0,050	7690	I200
0,040	8350	I300
0,0335	9220	I400
0,0285	I0500	I500
0,0256	I2990	I500
0,02I6	I34I0	I600
0,0I89	I3590	I700
0,0I64	I5320	I800
0,0I39	I6290	I900
0,0II9	I6700	2000
0,0100	23060	2500
0,0087	2I350	3000
0,0077	25550	3500
0,0065	32000	4000

Table 2

Westcott g-factor for europium-152 ($T_{\frac{1}{2}}$ = 12.4 years)

T°K	g
273	0,983
293	0,967
313	0,952
333	0,938
353	0,925
373	0,912
393	0,900
413	0,888
433	0,876
453	0,865
473	0,855
493	0,844

MEASUREMENT OF THE ABSORPTION CROSS-SECTION OF ^{152}Eu ($T_{\frac{1}{2}}$ = 12.4 YEARS) FOR THE THERMAL NEUTRON SPECTRUM

V.F. Razbudej, A.V. Muravitskij, V.I. Golyshkin,
A.F. Ogorodnik, I.F. Barchuk

The thermal-neutron cross-section of the long-lived isomer of ^{152}Eu was determined by the activation method with a neutron gas temperature of 333°K. To this end measurements were made of the relative activities of the isotope ^{152}Eu formed during irradiation of a sample of the stable isotope ^{151}Eu in the beryllium reflector of the VVR-M (water moderated and cooled) reactor. The integral thermal neutron doses were 2.23×10^{19}, 9.66×10^{19} and 1.64×10^{20} n/cm^2. The corresponding activities (in relative units) were: 1, 2.25 and 2.33. The neutron cross-sections were obtained by analysing the experimental values of the activities, using the equations of nuclear transformation kinetics.

The activities were measured from the line intensity of the gamma spectra from the decay of ^{152}Eu.

The measurements were performed in a spectrometer with a Ge(Li) detector (resolution 6 keV). To allow for the instability of the spectrometer parameters, a ^{152}Eu reference source was employed. The measured cross-section $\hat{\sigma}$ = 8900 ± 1100 barn.

MORE ACCURATE VALUES OF TOTAL NEUTRON CROSS-SECTIONS OF ^{153}Eu IN THE 0.008–0.3 eV ENERGY RANGE

V.F. Razbudej, A.F. Fedorova, A.V. Muravitskij

The total cross-sections of ^{153}Eu were measured in the 0.008–0.3 eV neutron energy range in Ref. [1]. The main source of errors was the uncertainty in the composition of the sample or, more precisely, the content of ^{151}Eu impurities and strongly absorbing isotopes of gadolinium. According to the certificate the sample contained 99.3% ^{153}Eu and 0.7% ^{151}Eu. The accuracy of these figures was not indicated. The concentration of gadolinium isotopes was not given in the certificate but their contribution to the total cross-section of the sample was estimated at 5 ± 3% by the authors of Ref. [1] from measurements of the capture gamma spectra [2].

An activation analysis of the ^{153}Eu sample used in Ref. [1] was performed in order to determine the ^{151}Eu impurity content more accurately. In addition, observation of the variation in the total cross-section of the sample during irradiation by a high flux of thermal neutrons enabled the conclusion to be drawn that gadolinium isotopes make no appreciable contribution to the cross-section of an unirradiated sample of ^{153}Eu. These experiments made it possible to improve the accuracy of the experimental values in Ref. [1] for the total cross-sections of ^{153}Eu over the whole neutron energy range.

Activation analysis of the sample

Two samples were prepared - a sample of ^{153}Eu (with ^{151}Eu impurity, the content of which had to be determined) and a sample of natural europium containing 47.82% ^{151}Eu and 52.18% ^{153}Eu. The samples were irradiated for 24 hours in vertical channel TK-3 of the thermal column of the VVR-M reactor and their gamma spectra were measured after a week's cooling. The measurements were performed in a gamma spectrometer using a Ge(Li)-detector with a resolution of 6 keV. Gamma rays are emitted by the radioactive ^{152}Eu and ^{154}Eu nuclei ($T_{\frac{1}{2}}$ = 12.4 and 8.6 years respectively) formed as a result of neutron capture by ^{151}Eu and ^{153}Eu nuclei during irradiation. The gamma spectrum of the irradiated europium samples is a combination of the ^{152}Eu and ^{154}Eu spectra. The ratio between the intensities of the lines belonging to ^{152}Eu and ^{154}Eu is

determined by the ratio of the ^{151}Eu and ^{153}Eu concentrations in the initial samples. The ^{151}Eu concentration in the ^{153}Eu sample is determined from the simple proportion:

$$\frac{I^{154}_{153}}{I^{152}_{153}} : \frac{I^{154}_{nat}}{I^{152}_{nat}} = \frac{1 - x}{x} : \frac{52.18}{47,82}$$

where x is the unknown ^{151}Eu concentration in the ^{153}Eu sample and I^{A}_{B} is the gamma line intensity of the isotope A in the irradiated sample B.

The ^{151}Eu impurity content of the ^{153}Eu sample determined in the activation experiment is 0.652 ± 0.04%.

Estimation of the contribution of gadolinium isotopes to the total cross-section of the ^{153}Eu sample

The gadolinium isotopes ^{155}Gd and ^{157}Gd have colossal thermal cross-sections of 61 000 and 250 000 barn. Therefore they must burn up almost completely when irradiated with an integral dose of ~2 x 10^{19} n/cm^2, and this effect should manifest itself as a reduction in the observed total cross-section of the irradiated ^{153}Eu sample by an amount equal to the assumed contribution of gadolinium to the cross-section of the unirradiated sample.

Table 1

Total neutron cross-sections of ^{153}Eu as a function of neutron energy

Energy in eV	Total cross-section in barns	Energy in eV	Total cross-section in barns	Energy in eV	Total cross-section in barns
0,I8	I00,3±2,8	0,II6	I25	0,082	I60
0,I72	I03	0,II3	I3I ± 2,5	0,079	I63 ± I,6
0,I65	I05	0,I09	I33	0,077	I64
0,I60	I05	0,I06	I35 ± 2,4	0,075	I68
0,I53	III,6±2,8	0,I03	I38 ± 2,3	0,073	I69
0,I48	II2,6	0,099	I40,4±2,2	0,072	I7I
0,I42	II5,7	0,097	I44 ± 2,0	0,069	I72±I,5
0,I37	II8,4	0,094	I47 ± I,9	0,068	I75
0,I33	I20,0±2,7	0,09I	I50 ± I,8	0,066	I75
0,I28	I2I	0,089	I53	0,065	I80±I,4
0,I24	I24 ± 2,6	0,086	I56	0,063	I84
0,I20	I25	0,084	I57,7±I,7	0,062	I88

Energy in eV	Total cross-section in barns	Energy in eV	Total cross-section in barns	Energy in eV	Total cross-section in barns
0,060	190±1,3	0,0413	233	0,024	305
0,059	192,4	0,0405	234±1,1	0,023	315
0,058	195	0,0397	238	0,022	322
0,056	196	0,039	243	0,021	327
0,055	198	0,038	246	0,02	334 ± 1,8
0,054	201	0,037	248	0,019	339
0,053	204	0,036	250	0,018	357 ± 2,0
0,052	205	0,035	253	0,017	369
0,051	209	0,034	257	0,016	381
0,049	212±1,3	0,033	260	0,015	392 ± 2,5
0,048	214	0,032	266	0,014	404
0,047	216	0,031	271	0,013	422 ± 3,0
0,046	218	0,030	278±1,3	0,012	435
0,045	220	0,029	280	0,011	453 ± 4
0,044	222	0,028	280	0,010	470 ± 5
0,0438	225	0,027	287	0,0055	475
0,0429	226	0,026	298	0,0090	499
0,0421	230	0,0253	300±1,5	0,0085	526
				0,0080	558

However, no reduction was observed in the cross-section of the irradiated ^{153}Eu sample [3]. This indicates that the concentration of strongly absorbing gadolinium isotopes is very small and makes only an insignificant contribution to the total cross-section of the ^{153}Eu sample.

The contribution of gadolinium to the total cross-section of the ^{153}Eu sample, estimated from our experiments to measure the total cross-section of the ^{153}Eu sample irradiated with thermal neutrons, is equal to 0^{+1}_{-0}%. We averaged this value and the value of 5 ± 3% from Ref. [1] with a weight inversely proportional to the error and obtained 1.25 ± 1.25%.

Results

The total cross-sections of ^{153}Eu were corrected in accordance with the new data on the impurity content of the sample and the refined values are given in Table 1. Corrections were introduced for both the ^{151}Eu and the gadolinium impurities. The statistical errors are also given in the table.

Table 2 lists the sources of possible uncertainties and indicates the maximum values of the systematic errors.

Table 2

Maximum values of the systematic errors possible in the total cross-sections of ^{153}Eu

Source of error	Relative error in ^{153}Eu cross-sections (%)
Uncertainty of gadolinium contribution	1.25
Uncertainty of ^{151}Eu contribution	1.15
Uncertainty of dimensions of sample	1.1
Uncertainty of weight of sample	0.6

Two methods are recommended for calculating the total systematic measuring error [7]:

$$\Delta\sigma = \sum_{i}^{0} \Delta\sigma \qquad (1)$$

for a small number of error sources, and

$$\Delta\sigma = \sqrt{\sum_{i} (\Delta\sigma i)^2} \qquad (2)$$

for a large number. The total systematic error in the ^{153}Eu cross-section calculated according to Eq. (1) is 4%, and calculated according to Eq. (2), 2%. It seems reasonable to take the systematic error as 3% by way of compromise between approaches (1) and (2).

The statistical accuracy in the measured energy range is in the range 0.5-2.8%. For neutrons with a velocity of 2200 m/sec the total error is ± 3.5%. Table 3 compares the total and partial neutron cross-sections of ^{153}Eu for a neutron velocity v = 2200 m/sec obtained by us and other authors.

Table 3

Neutron cross-sections of ^{153}Eu for v = 2200 m/sec

Reference	Year	σ_t, barn	σ_s, barn	σ_γ, barn
Vertebnyj 1	1973	282±14		274±14
Vertebnyj 2	1970		8 ± 0,3	
Pattenden 3	1958			448±16
Tattersal 4	1965			319±5
Sims 5	1967			678±8
Hayden 6	1949			425±125
This paper		300±10		292±11
Recommended by authors		308±10	8 ± 0,3	300±11

Such scatter in the data of the different authors is evidently caused by the considerable content of strongly absorbing impurities in the samples. In Ref. [1] the measurements were performed on the most highly enriched samples.

The energy dependence of the absorption cross-section obtained by subtracting the scattering cross-section (8 ± 0.3 barn), which is constant over this energy range [2], was used to obtain the Westcott g-factor:

$$\frac{1}{v^2\sigma_0}\int_0^\infty \frac{4}{\sqrt{\pi}}\frac{v^3}{v_T^3}e^{-(v/v_T)^2}\sigma(v)dv$$

where σ_0 is the absorption cross-section for neutrons with velocity v_0 = 2200 m/sec and $v_T = v_0\sqrt{T/T_0}$; T_0 = 293.6°K and T is the temperature of the neutron spectrum.

Beyond the limits of the measured energy range we used extrapolated absorption cross-sections calculated from the Breit-Wigner formula. The parameters of levels with positive energy were taken from Ref. [9]; the parameters of a level with negative energy were determined by fitting the curve calculated from the Breit-Wigner formula to experimental values of the absorption cross-sections in the thermal energy range by varying the radiation width Γ_γ and the reduced neutron width Γ_n^0 of the level and its position E_0 (E_0 = 0.7 eV, $2g\Gamma_n^0$ = 0.59 meV, Γ_γ = 95.8 meV). The g-factors in the 293-403°K temperature range of the neutron spectrum are shown in Table 4.

Table 4

Westcott g-factors for ^{153}Eu as a function of temperature

T°K	g	T°K	g
293	0,983 ± 0,06	353	0,976 ± 0,06
303	0,983 ± 0,06	363	0,975 ± 0,05
313	0,981 ± 0,06	373	0,974 ± 0,05
323	0,980 ± 0,06	383	0,972 ± 0,05
333	0,979 ± 0,06	393	0,971 ± 0,05
343	0,978 ± 0,06	403	0,970 ± 0,05

REFERENCES

[1] VERTEBNYJ, V.P., VLASOV, M.F., ZATSERKOVSKIJ, G.A. et al., Proc. 1st Neutron Physics Conf. Kiev, part 2 (1973) 239.

[2] VERTEBNYJ, V.P., VLASOV, M.F., GNIDAK, N.L. et al., in Nuclear Data for Reactors (Proc. Conf. Helsinki, 1970) 1, IAEA, Vienna (1970) 651.

[3] Pattenden N.F. Second Geneva Conf.,1958, Paper P/11, v.16, p.45.

[4] Tattersal R.B. et al. J.Nucl.Energy, 1960, v.12, p.32.

[5] Sims C.H., Juhnke D.G. J.Inorg.Nucl.Chem.1967, v.29, p.2671.

[6] Hayden R.I. et al. Phys.Rev.,1949, 75,1500.

[7] Granberg B. et al. Atomic Energy Review, 1973, 11,515.

[8] RAZBUDEJ, V.F.,et al., Kiev Nuclear Research Institute preprint KIYaI-75-17 (1975).

[9] Neutron cross-section, vol.1 Resonance parameters, BNL-325, third edition,1973.

Lensovet Leningrad Technological Institute

RELATIVE YIELDS OF XENON ISOTOPES DURING PHOTOFISSION OF ^{237}Np AND ^{235}U

K.A. Petrzhak, E.V. Platygina, Yu.A. Solov'ev, V.F. Teplykh

Xenon isotopes with A = 131–136 are situated in that region of the fragment mass spectrum in which many authors have observed the finest yield structure during fission of a whole series of atomic nuclei [1–5].

The most accurate values of the absolute and relative yields of fragments were obtained by mass spectrometry during thermal and fast fission of thorium, uranium and plutonium isotopes and other heavy nuclei. The yields during photofission were largely investigated by the less accurate radiochemical method, as the amount of fragments accumulated under normal irradiation conditions is insufficient for mass spectrometric analysis.

The relative yields of xenon isotopes with A = 131–136 during bremsstrahlung-induced fission of ^{237}Np and ^{235}U were measured by the authors with a high-sensitivity mass spectrometer. The irradiations were performed in the B-30 betatron of the Leningrad Technological Institute. Targets of neptunium dioxide and uranium mixed oxide in the form of tablets weighing 1 g were placed close to the orbit of the accelerated electrons in the device described in Ref. [6] to increase the absorbed dose. After an irradiation time of 40–50 hours the total amount of fission xenon was around 10^{-9} cm^3. After two months' retention the noble gases were extracted from the targets by the thermal method in a quartz vacuum system. The gases were scrubbed by the standard method described in Ref. [7].

The xenon fragment spectra measured during photofission of ^{237}Np at maximum bremsstrahlung energies of 15 and 20 MeV, and of ^{235}U at a maximum bremsstrahlung energy of 20 MeV, are presented in Table 1. The results obtained indicate the presence of fine structure of the fragment yield curve with a peak at mass 134. The energy dependence during fission of ^{237}Np is also noticeable. The yield of fragments with A = 134 decreases and that of fragments with A = 131 increases with increasing excitation energy of the fissioning nucleus.

Table 1

Relative yields of Xe isotopes during photofission of ^{237}Np and ^{235}U

Fissioning nucleus	Maximum bremsstrahlung energy, MeV	Isotopic composition, %			
		^{131}Xe	^{132}Xe	^{134}Xe	^{136}Xe
^{237}Np	20	21,50±0,60	23,00±0,70	29,10±0,50	26,40±0,40
^{237}Np	15	19,70±1,20	21,40±1,50	31,80±1,10	27,10±0,90
^{235}U	20	20,00±0,20	24,20±0,30	28,50±0,20	27,30±0,20

Translator's note: The list of references has been omitted.