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Institute of Physics and Power Engineering

RELATIVE YIELDS OF DELAYED NEUTRONS FROM ^{237}Np FISSION BY 0.4-1.2 MeV NEUTRONS

B.P. Maksyutenko, Yu.F. Balakshev,
G.I. Volkova

The authors measured the relative yields of delayed neutrons from ^{237}Np fission by 0.4-1.2 MeV neutrons obtained through the reaction $T(p,n)^3He$ from a target 1 mg/cm^2 thick.

The relative yields of the different groups were calculated on the basis of curves showing the decline of the neutron activity for given half-lives by the least-squares method. The results are presented in the following table.

The yield ratio varies smoothly within the energy range in question.

Table 1

Relative yields of groups of delayed neutrons from ^{237}Np fission

Group No.	$T_{½}$ (sec)	Relative yields (a_i/a_1)		
		E_n=0.4 MeV	E_n=0.5 MeV	E_n=0.6 MeV
1	54,28	I	I	I
2	23,04	7,47±0,21	8,11±0,20	7,69±0,11
3	5,6	6,56±0,39	8,53±0,32	8,39±0,19
4	2,13	15,5 ±1,1	17,0 ±0,9	14,7 ±0,5

Table 1 (continued)

Group No.	$T_{½}$ (sec)	Relative yields (a_i/a_1)		
		E_n=0.7 MeV	E_n=0.8 MeV	E_n=0.9 MeV
I	54,28	I	I	I
2	23,04	7,47±0,I7	7,40±0,08	7,57±0,06
3	5,6	7,4I±0,4I	7,76±0,I4	8,76±0,09
4	2,I3	I4,4 ±0,8	I4,0 ±0,4	I2,48±0,25

Table 1 (continued)

Group No.	$T_{½}$ (sec)	Relative yields (a_i/a_1)		
		E_n=I.0 MeV	E_n=I.I MeV	E_n=I.2 MeV
I	54,28	I	I	I
2	23,04	7,I6±0,I0	7,39±0,09	7,36±0,I8
3	5,6	8,I8±0,I4	8,I7±0,I6	8,85±0,3I
4	2,I3	I2,9±0,6	I6,5 ±0,5	I6,2 ±I,4

MEASUREMENTS OF $\bar{\alpha}$ FOR ^{235}U IN FILTERED NEUTRON BEAMS FROM THE OBNINSK POWER REACTOR

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(Article submitted to "Atomnaja energija")

The authors present results obtained by measuring $\bar{\alpha} = \bar{\sigma}_c/\bar{\sigma}_f$ for ^{235}U and averaging most of the currently available data on this parameter. The measurement results are compared with the results of differential experiments and of calculations based on different systems of constants. The measurements wer performed in filtered, quasi-monoenergetic neutron beams from the Obninsk power reactor. The method employed, the experimental set-up, the geometry and the filtered neutron beam spectra have been described in Refs 1 and 2. The measurements were performed in beams with energies of 2.0 keV, 24.5 keV and 140 keV and in a "boron-filtered" beam with a "soft" continuous spectrum, using samples of 90%-enriched metallic ^{235}U (thickness 0.004 nuclei/barn and 0.006 nuclei/barn) welded into stainless steel sheaths 0.2 mm thick. "Equivalent" scatterers made of lead were used for estimating the gamma and neutron background. The results of the calibrated measurements were normalized to $\bar{\alpha}^{th}$ calculated from evaluated UKNDL and ENDF/B-III cross-sections, which was found to be 0.187 ± 0.007 allowing for uncertainty in the neutron spectrum.

In the calculations of $\bar{\alpha}$ from the measurement results, corrections were made for gamma-ray and neutron scattering, absorption and multiplication in the ^{235}U samples, for the presence of ^{238}U and for the fact that the neutron beams were not monoenergetic.

The $\bar{\alpha}$ values for ^{235}U obtained by the authors for three neutron energy groups are presented in Table 1, together with the mean-square errors calculated with allowance for normalization uncertainties, correction coefficients, statistical errors and their correlations.

Table 1

Values of $\bar{\alpha}$ obtained by performing measurements in filtered neutron beams

Thickness of ^{235}U sample (nuclei/barn)	Neutron energy range (keV)			
	I,5-2,3	22,9-25,4	I23-I5I	"continuous" spectrum
0,004	0,468±0,033	0,36I±0,038	0,2I4±0,030	0,362±0,022
0,006	0,454±0,03I			

The results of averaging the $\bar{\alpha}$ data for ^{235}U from most experiments performed in the neutron energy range 0.1–800 keV are presented in Table 2. Averaging of the data was performed with uniform statistical weighting after a correction for the $\bar{\alpha}$ blocking effect had been introduced in those cases where the effect was greater than 1% and no correction had been made by the authors. The error in Table 2 is the mean-square deviation from the mean.

Table 2

Results of averaging $\bar{\alpha}$ values for ^{235}U in the neutron energy range 0.1–800 keV

Energy group (keV)	$\bar{\alpha}$ ^{235}U	Energy group (keV)	$\bar{\alpha}$ ^{235}U	Energy group (keV)	$\bar{\alpha}$ ^{235}U	Energy group (keV)	$\bar{\alpha}$ ^{235}U
0,1-0,2	0,650±0,054	1-2	0,412±0,018	10-15	0,360±0,021	100-200	0,246±0,008
0,2-0,3	0,494±0,027	2-3	0,417±0,030	15-20	0,386±0,006	200-300	0,204±0,008
0,3-0,4	0,480±0,034	3-4	0,422±0,048	20-30	0,348±0,010	300-400	0,173±0,006
0,4-0,5	0,362±0,011	4-5	0,383±0,026	30-40	0,359±0,008	400-500	0,154±0,005
0,5-0,6	0,314±0,020	5-6	0,316±0,024	40-50	0,345±0,012	500-600	0,140±0,007
0,6-0,7	0,424±0,017	6-7	0,372±0,022	50-60	0,321±0,018	600-700	0,127±0,011
0,7-0,8	0,445±0,022	7-8	0,362±0,034	60-70	0,306±0,019	700-800	0,124±0,007
0,8-0,9	0,477±0,041	8-9	0,379±0,027	70-80	0,303±0,021		
0,9-1,0	0,532±0,037	9-10	0,342±0,034	80-90	0,301±0,201		
				90-100	0,299±0,020		

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[2] KUZIN, E.N. et al., Atommaja energija 35, issue 6 (1973) 391.

ABSOLUTE MEASUREMENT OF THE RADIATIVE CAPTURE OF NEUTRONS BY ^{238}U

Yu.G. Panitkin, L.E. Sherman

Using the absolute, activation method, the authors measured the cross-section for the radiative capture of neutrons by ^{239}U at an energy of 30 keV. Kinematic collimation of neutrons in the reaction $^{7}Li(p,n)^{7}Be$ was used.

The neutron flux was measured by the associated-activity method taking the 477-keV gamma radiation accompanying the decay of the ^{7}Be formed in the reaction $^{7}Li(p,n)^{7}Be$.

The induced activity of the ^{238}U samples was measured by taking the 74-keV gamma radiation associated with the decay of ^{239}U.

The efficiency of the gamma spectrometer used for the uranium and beryllium samples was determined by means of a 4π beta counter.

The results of the absolute measurements were used for normalizing the energy dependence of the cross-section for the radiative capture of neutrons by ^{238}U measured in other studies [1-3]. The absolute values are presented in Table 1.

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[3] PANITKIN, Yu.G. et al., proceedings of a meeting on neutron physics, Kiev (1972); published by Naukova dumka.

Table 1

Cross-section for the radiative capture of neutrons by ^{238}U

E_n, (keV)	σ_c, (mbarn)
24 ± 8	500 ± 27
30 ± 6	465 ± 23*/
35 ± 8	426 ± 24
45 ± 8,5	37I ± 9
55 ± 9	357 ± I9
65 ± I0	300 ± I5
75 ± I0,5	276 ± I4
85 ± II	240 ± I3
I05 ± II,5	205 ± I0
I25 ± I2,5	I8I ± 9
I45 ± I3,5	I65 ± 8,5
200 ± I8	I45 ± 7,5
250 ± I9	I32 ± 6,8
300 ± I9	I22 ± 6,3
400 ± I9,5	II4 ± 6
500 ± 22	I08 ± 5,6
600 ± 34	I08 ±5,6
700 ± 35	II4 ± 5,9
800 ± 36	II6 ± 6
900 ± 36	II6 ± 6
I000 ± 39	I09 ± 5,7
II00 ± 4I	I06 ± 5,5
I200 ± 43	9I ± 4,8

E_n, (MeV)	σ_c, (mbarn)
I,3±0,045	80 ± 4,3
I,5±0,049	60 ± 3,2
I,8±0,054	47 ± 2,6
2,0±0,057	39 ± 2,I
2,2±0,06I	32 ± I,8
2,5±0,067	26 ± I,5
2,8±0,073	2I ± I,3
3,0±0,078	I8 ± I,I
3,5±0,094	I6 ± I,5
4,0±0,II0	I3 ± I,I
5,0±0,II5	8 ±I,I
6,0±0,I36	6,8 ± I,0
7,0±0,I60	5,8 ± I,I
I5,0±0,I50	3,3 ± I,47
I6,0±0,200	3,0 ± I,3
I7,0±0,260	3,7 ± I,3
I8,0±0,235	3,3 ± I,2
I9,0±0,250	2,9 ± I,4
20,0±0,285	[illegible],4 ± I,9

*/ At a neutron energy of 30 keV, the radiative capture cross-section is measured absolutely.

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MEASUREMENT OF THE CROSS-SECTION FOR ^{249}Cf FISSION BY 0.25-5.15 MeV NEUTRONS

E.F. Fomushkin, E.K. Gutnikova, G.F. Novoselov

Using dielectric track detectors, the authors measured the curve of the cross-section for ^{249}Cf fission by neutrons with energies in the range 0.25-5.15 MeV. The measurements were performed in an EG-5 electrostatic accelerator; the neutrons were obtained by means of the reaction T(p,n). The neutron flux was determined by using dielectric detectors to measure the number of fission events in a reference layer of ^{235}U. The number of nuclei in the layer being investigated and in the reference layer was measured on the basis of fission by thermal neutrons in a graphite column. The measurement results are presented in Table 1.

The error shown in the table is a statistical one. The "absolutization" error (±4.9%) is due almost entirely to the error in the cross-section for ^{249}Cf fission by thermal neutrons.

Table 1

E_n, (keV)	ΔE_n	$\sigma_f\ ^{249}Cf$	$\Delta\sigma_f/\sigma_f$
250	80	I,9I	4,8
350	65	I,80	4,4
450	60	I,63	4,2
570	60	I,59	4,3
670	55	I,50	4,4
770	50	I,42	4,2
930	45	I.3I	4,7
I090	45	I,29	4,5
I250	45	I,46	4,I
I400	40	I,80	4,0
I560	40	2,03	4,0
I760	40	2,I4	3,8
I860	40	2,I2	3,9
2000	40	2,20	3,7
2I50	40	I,9I	3,8
2300	40	I,97	3,7
2450	40	I,8I	3,4
2600	40	I,86	3,6
2760	45	I,92	3,3
3060	45	I,72	4,0
3360	50	I,64	3,9
3660	50	I,6I	4,2
3960	50	I,68	4,I
4260	55	I,66	4,4
4550	55	I,7I	5,6
4850	60	I,60	6,0
5I50	65	I,80	6,5

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FINE STRUCTURE OF THE ENERGY SPECTRA OF ^{252}Cf SPONTANEOUS FISSION FRAGMENTS

I.A. Baranov, G.A. Tutina

Using semiconductor detectors, the authors investigated the fine structure of the energy distributions of ^{252}Cf spontaneous fission fragments. It is shown with statistical certainty that such a structure exists in the energy distributions of the heavy fission fragment if the energy of the light fragment is fixed at very high values (E_{light} = 116.5-124 MeV). Fission fragment pairs with the masses (87-165), 92-160, 98-154, 102-150, 108-144 and 113-139 have higher yields. In the case of the pair in brackets, the higher yield was established with less certainty. The influence of some of these pairs is also noted in mass distributions when the total kinetic energy of the fission fragments is fixed.

SYMMETRIC AND ASYMMETRIC PHOTOFISSION OF ^{226}Ra

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Yu.M. Tsipenyuk

(Article submitted to "Jadernaja fizika")

The authors set themselves the task of investigating the contributions of the symmetric and asymmetric components of ^{226}Ra photofission as a function of the bremmsstrahlung boundary energy at angles of 0° and 90° to the photon beam. For this they measured the track diameter spectra of the fission fragments in glass detectors with filters. On the basis of these spectra they separated out the symmetric and asymmetric fission components. The measurements were performed for bremsstrahlung spectrum boundary energies E_o = 11-28 MeV. In this boundary energy range, the contribution of the symmetric component varies from 0.12 to 0.5. At all energies, excitations of anisotropy and of asymmetric fission coincide within the error limits. A contribution of the symmetric component is found in the excitation region, where the post-emission fission of radium is excluded.

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INVESTIGATION OF THE CHARACTERISTICS OF SOURCES AND FIELDS OF MONOENERGETIC p,n-NEUTRONS IN ELECTROSTATIC ACCELERATORS

R.D. Vasiliev, S.G. Kondratenko

The authors describe the precision apparatus for, and consider methodological questions associated with, measurements of the yield and the flux density of monoenergetic neutrons from p,n nuclear reactions.

For determining the neutron yield they used the manganese bath and the associated radionuclide methods.

The flux density was found experimentally by means of a two-sphere manganese bath and theoretically through yield calculations on the basis of the angular distributions of the neutrons. At the same time, the flux density was measured by means of a long counter of known efficiency.

A system for stabilizing the yield (flux density) - for keeping it steady within the requisite limits - was used to reduce the systematic errors in measuring the characteristics of the neutron fields.

RESULTS OF INVESTIGATIONS OF A STANDARD FIELD OF THERMAL NEUTRONS

R.D. Vasiliev, V.P. Yaryna, N.N. Pupchenko, V.S. Tsoi

(Article submitted to "Jadernye konstanty")

A standard field of thermal neutrons is created within a cubic cavity in a moderator assembly of graphite and organic glass. The neutrons are produced by the reaction $T(d,n)^4He$ in two targets set up in the assembly. A special stabilization system keeps the neutron flux intensity steady during the experiments. The measurement of the neutron flux density is reproduced with an error of no more than 2% at the 95% confidence level within the flux density range 10^4-10^7 neutrons/$cm^2 \cdot s$.

The authors present the results of investigations of the characteristics - uniformity and isotropy, cadmium ratio, effective temperature of thermal neutrons, energy distribution of epithermal neutrons, contribution of fast neutrons, etc. - of the neutron field in the working cavity.

The standard field of thermal neutrons is intended for precision integral activation studies with samples of different substances.

Leningrad Technological Institute

FISSION FRAGMENT YIELDS AND REACTION CROSS-SECTIONS FOR ^{232}Th, ^{238}U, ^{237}Np AND ^{239}Pu PHOTOFISSION BY PHOTONS WITH MAXIMUM ENERGIES OF 5-12 MeV

K.N. Ivanov, K.A. Petrzhak

(Article submitted to "Jadernye konstanty")

The authors obtained information about the yields in ^{232}Th, ^{238}U, ^{237}Np and ^{239}Pu photofission by photons with maximum energies of 5-12 MeV and determined the observed fission thresholds and the influence of the competing reaction (γ,n) on the energy dependence of the fission cross-sections. A betatron was used as bremsstrahlung source. The fission fragments were recorded by means of mica detectors. The photofission yield curves were converted to cross-sections by the Penfold-Leiss method. All the cross-sections are characterized by singularities - inflections in the photon energy region 5-8 MeV. The observed structure is attributable to sub-barrier fission (at 5.35 MeV and 5 MeV in the case of ^{232}Th and ^{238}U), to the competing (γ,n) reaction and to the influence of nucleon pairing on the displacement of the observed fission thresholds along the energy scale.

Scientific Research Institute for Pulse Technology

USE OF THE MAXIMUM LIKELIHOOD METHOD IN DETERMINING THE PARAMETERS OF AN EXPONENTIAL FUNCTION

A.A. Greshilov, I.A. Petukhova

(Article submitted to "Jadernye konstanty")

Using the maximum likelihood method, the authors consider the determination of the parameters of an exponential function on the basis of given experimental points. Errors occur along both co-ordinate axes. The authors present the results of calculations performed with the initial data set forth in different ways and for different arrangements of the points along the co-ordinate axes.

OBTAINING THE PARAMETERS OF A GAUSSIAN FUNCTION BY THE MAXIMUM LIKELIHOOD METHOD

A.A. Greshilov, L.A. Piskareva

(Article submitted to "Jadernye konstanty")

The authors describe a way of obtaining estimates of the free parameters (σ, A, t_o) of the Gaussian function

$$y(t) = \frac{A}{\sqrt{2\pi}\,\sigma} \exp\left[-\frac{(t-t_0)^2}{2\sigma^2}\right] \cdot f(t, \bar{a}), \tag{1}$$

by the maximum likelihood method with allowance for the errors along the two co-ordinate axes for the following cases:

1. A discrete set of values specified for the co-ordinates of the experimental points;
2. The values of the integrals y_K taken between the limits $[t_{K-1}, t_K]$ are known for a discrete set of values of $\{t_K\}$.

With the maximum likelihood method, an estimate of the free parameters of a known function is obtained from the system

$$\frac{\partial \ln F(\bar{a}, \xi)}{\partial \bar{a}'} = \theta, \tag{2}$$

in the case of $\bar{a}^{-1}$, where $\bar{a}$ is a vector of the unknown parameters,

P is the probability distribution density of the experimental points,

$\bar{\theta}$ is a zero vector [1].

It was assumed that the experimental values had a Gaussian distribution and were independent. The probability distribution density of the experimental points is in this case described by the expression

$$P = \prod_K \frac{1}{2\pi\sigma_{t_K}\sigma_{y_K}} \exp\left\{-\frac{1}{2}\left[\frac{(t_K - \langle t_K\rangle)^2}{\sigma^2_{t_K}} + \frac{(y_K - \langle y_K\rangle)^2}{\sigma^2_{y_K}}\right]\right\}, \qquad (3)$$

where the abscissa and ordinate of the measured K-th point are denoted by t_K, y_K and $\langle t_K\rangle$, $\langle y_K\rangle$ are the corresponding expected values. For a Gaussian function the system (2) is rewritten:

$$\frac{\partial \ln P}{\partial a_i} = \sum_K \left(\frac{t_K - \langle t_K\rangle}{\sigma^2_{t_K}} \frac{\partial\langle t_K\rangle}{\partial a_i} + \frac{y_K - \langle y_K\rangle}{\sigma^2_{y_K}} \frac{\partial\langle y_K\rangle}{\partial a_i}\right) = 0, \qquad (4)$$

$$i = 1,\ 2,\ 3$$

Here, the expected values of $\langle t_K\rangle$ were determined not from the condition

$$\frac{\partial \ln P(\bar{a},\bar{t})}{\partial\langle t_K\rangle} = 0 \qquad (5)$$

while $\langle y_K\rangle = f(\langle t_K\rangle)$ on the basis of formula (1). However, $\langle t_K\rangle = t_0 + \sigma\sqrt{2\ln(A/\sqrt{2\pi}\,\sigma_{y_K})}$ and $\langle y_K\rangle = f(t_K, a)$.

The system (4) was solved, with allowance for the conditions (5), by the iteration method.

Inversing the matrix of the second derivatives from $\ln P$,

$$\left[\frac{\partial^2 \ln P}{\partial a_i\,\partial a_j}\right]_{\bar{a}=\bar{a}'}$$

$$i,j = 1,2,3$$

the authors find, with an accuracy to within higher-order terms, the matrix of the errors in the unknown parameters, where the dispersions of $\bar{a}$ taken with inverse signs are on the main diagonal.

The resulting system of non-linear transcendental equations, system (4), was solved by the Newton linearization method [2].

The main results were as follows.

With a zero approximation differing by ≈40% from the true values of the unknown parameters, the calculations (using a Minsk-22 computer) lasted 10-15 min, and involved 10-30 iterations, the sum of the squares of final errors not in excess of 0.01 being obtained.

For discrete pulse specification it was determined how to distribute a given number of points within the interval being measured in such a way that the parameters were found with maximum accuracy. The lowest dispersion with respect to the parameter σ was taken as the criterion. This parameter assumed its minimum value for the selection of t_K when the integrals taken in these closed intervals $[t_{K-1}, t_K]$ were constant.

The results can be used in many cases for the analysis of experimental data when one must not neglect the error in the argument of a function.

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