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NUCLEAR PHYSICS RESEARCH IN THE USSR

COLLECTED ABSTRACTS

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Institute of Physics and Energetics

MEASUREMENTS OF α FOR ^{239}Pu IN FILTERED BEAMS OF REACTOR NEUTRONS

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The authors present the final results of measurements of $\langle\alpha\rangle = \langle\sigma_c\rangle/\langle\sigma_f\rangle$ for ^{239}Pu in scandium (2 keV), iron (24.5 keV) and silicon (140 keV) filtered beams of neutrons from the uranium-graphite reactor of the Obninsk Nuclear Power Station.

The method employed, the apparatus and the experimental geometry and other conditions have been described in Refs [1,2]. The results presented below are normalized to α^{th} computed from capture and fission cross-sections [3,4,5] for a sub-cadmium neutron spectrum in which calibration measurements have been performed. The value of α^{th} for ^{239}Pu was found to be 0.589 ± 0.027 with allowance for uncertainties as regards the neutron spectrum and the cross-sections.

For the measurements in the filtered neutron beams, use was made of Pu discs weighing 10 g and 30 g, containing ~98.5% ^{239}Pu (principal impurities ^{240}Pu and Ga) and welded into stainless steel jackets ~0.2 mm thick.

For estimating the background of neutrons and gamma rays occurring in the scattering of the beam neutrons on the nuclei of the sample, use was made of equivalent Pb scatterers and mock-ups of the steel jackets. The filtered beam neutron spectra shown in Figs 1-4 were measured with proportional recoil proton counters and a scintillation spectrometer.

The main characteristics of the filtered beams and the background conditions of the measurements with a Pb sample weighing ~10 g are presented in Table 1 for a reactor power ~12 MW(th).

Table 1

Neutron energy (keV)	2.0	24.5	140
Energy width (keV)	0.8	2.5	28
Flux (neutrons/$cm^2 \cdot s$)	5×10^4	1.6×10^4	7×10^4
Widths of main filters (g/cm^2)	219 Sc 6.7 Ti 0.6 Cd	162 Fe 40.5 Al 5.7 S 0.2 ^{10}B	118 Si 7.9 Ti 2.5 ^{10}B
Width of additional filters for estimating background (g/cm^2)	4.5 Mn	3.4 Ti	
Fraction of neutrons not of the basic energy in the filtered spectrum (%)	19	6	20
Ratio of filtered radiation to sum of all backgrounds except the delayed radiation background for gamma rays, $E_e \geq 0.6$ MeV	1.8	0.5	0.5
for neutrons, $E_p \geq 1.8$ MeV	2.0	1.1	3.6

In the calculation of the values of α, corrections were introduced for effects caused by the ^{240}Pu and Ga impurities, for neutron and gamma-ray scattering, absorption and multiplication in the Pu samples and for the fact that the neutron beams were not monoenergetic. Table 2 gives the final results of the measurements of α for ^{239}Pu together with the associated mean-square errors, which were calculated with allowance for the uncertainties as regards α^{th}, the correction coefficients, the statistical errors and the internal correlation dependences.

Table 2

Sample thickness (nuclei/barn)	($2 \pm ^{0.3}_{0.5}$ keV)	($24.5 \pm ^{0.9}_{1.6}$ keV)	($140 \pm ^{11}_{17}$ keV)
1.45×10^{-2}	1.284 ± 0.066	-	-
4.85×10^{-3}	1.346 ± 0.078	0.384 ± 0.036	0.122 ± 0.021

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Fig. 1 Spectrum of scandium-filtered neutrons from power reactor

Key: 1. Neutron energy (keV)

2. Neutron flux per lethargy unit (relative units)

3. Filtered neutron spectrum

Filter effect + background	
Scandium	219 g/cm^2
Titanium	6.7
Cadmium	0.6
Background	
Scandium	219 g/cm^2
Titanium	6.7
Manganese	4.5

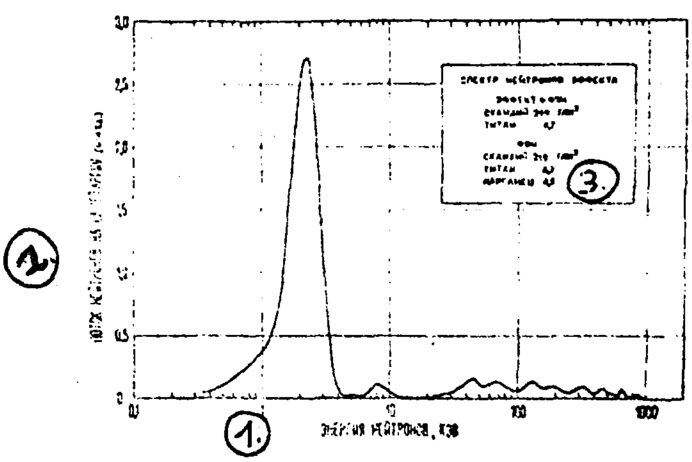

Рис. I. Спектр нейтронов эффекта скандиевого пучка реактора АЭС.

Fig. 2 Spectrum of 2-keV peak neutrons after correction for resolution function

Key: 1. Neutron energy (keV)

2. Neutron flux per lethargy unit (relative units)

3. 2-keV peak of spectrum resulting from scandium filtering of neutron beam from reactor of Obninsk Nuclear Power Station

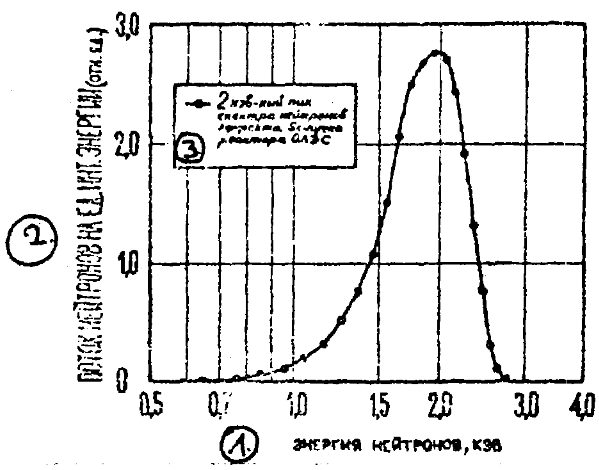

Рис. 2. Спектр нейтронов 2 кэв-ного пика после внесения поправки на функцию разрешения.

Fig. 3 Spectrum of beam of iron-filtered neutrons from power reactor

Key: 1. Neutron energy (keV)

2. Neutron flux per lethargy unit (relative units)

3. Filtered neutron spectrum

Filter effect + background	
Iron	162 g/cm^2
Aluminium	40.5 "
Sulphur	5.7 "
Boron-10	0.2 "
Background	
Iron	162 g/cm^2
Aluminium	40.5 "
Sulphur	5.7 "
Titanium	3.4 "
Boron-10	0.2 "

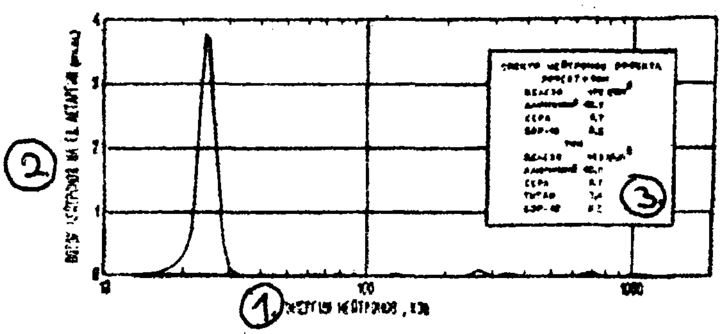

Рис. 3. Спектр нейтронов эффекта железного пучка реактора АЭС.

Fig. 4 Spectrum of silicon-filtered neutron beam

Key: 1. Neutron energy (keV)

2. Neutron flux per lethargy unit (relative units)

3. Silicon 118 g/cm^2
Titanium 7.9 "
Boron-10 2.5 "

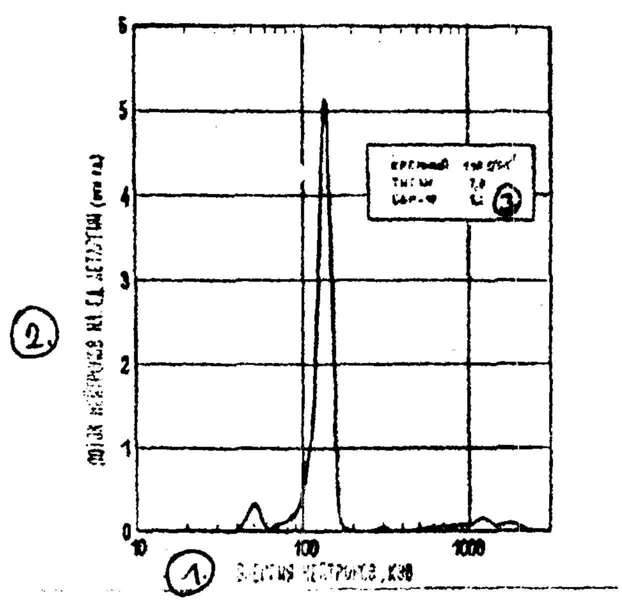

Рис. 4. Спектр нейтронов кремниевого пучка.

RELATIVE YIELDS OF DELAYED ^{233}U NEUTRONS IN FISSION BY NEUTRONS WITH ENERGIES OF 0.4 ± 1.1 MeV

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

The dependence of the relative yields of delayed ^{233}U neutrons on the energy of fission-inducing neutrons with energies of 0.4 ± 1.1 MeV was investigated.

The measurements were performed in a KG-2.5 accelerator. The thickness of the target used for obtaining the neutrons in the reaction $T(p,n)^3He$ was ~0.9 mg/cm^2. The sample was U_3O_8 powder weighing ~13 g.

Two series of neutron activity decay curves (10-20 measurements) were recorded, so that the integral count of each of them was 0.7 x 10^6 pulses (without background). The background was ~1% of the initial count rate. Recording took 1024 seconds. The neutron activity decay curves were processed in the interval 5-790 seconds - the first 60 seconds with an interval of one second and all the remaining time with an interval of ten seconds. The total interval was limited (to 790 s instead of 1024 s) because of the volume of the computer memory. However, the difference in the background value as between expansion of a curve by the least-squares method and direct determination of the background over the last 300 s is insignificant.

Values for the relative yields of four groups of delayed neutrons were obtained from the neutron activity decay curves as a result of processing by the least-squares method. The half-life values were taken from Ref. [1] for the case of fission by thermal neutrons.

The results are presented in Table 1 and Fig. 1. For easier visualization, the yield ratio is shown for each series in Fig. 1. Where the yields are for practical purposes the same, the value has been placed in a circle.

The data show that, for ^{233}U and for neutrons with energies of 0.4 ± 1.1 MeV, no change is observed in the yield ratio of the groups within the limits of the experimental errors.

Table 1

Relative yields of delayed neutrons in ^{233}U fission

$T_{1/2}$ (s)	E_n (MeV)	0,4 a_i/a_1	0,5 a_i/a_1	0,6 a_i/a_1
55,0		I	I	I
20,57		3,051 ± 0,062	3,163 ± 0,016	3,06 ± 0,13
5,0		3,768 ± 0,078	3,738 ± 0,011	3,62 ± 0,16
2,13		4,63 ± 0,33	4,01 ± 0,38	4,65 ± 0,12

$T_{1/2}$ (s)	E_n (MeV)	0,7 a_i/a_1	0,8 a_i/a_i	0,9 a_i/a_1
55,0		I	I	I
20,57		3,005 ± 0,076	3,104 ± 0,040	3,106 ± 0,015
5,0		3,70 ± 0,14	3,476 ± 0,066	3,7002 ± 0,0020
2,13		3,847 ± 0,015	5,091 ± 0,056	5,05 ± 0,24

$T_{1/2}$ (s)	E_n (MeV)	1,0 a_i/a_1	1,1 a_i/a_1
55,0		I	I
20,57		3,087 ± 0,023	3,103 ± 0,028
5,0		3,53 ± 0,10	3,594 ± 0,093
2,13		4,44 ± 0,18	4,34 ± 0,37

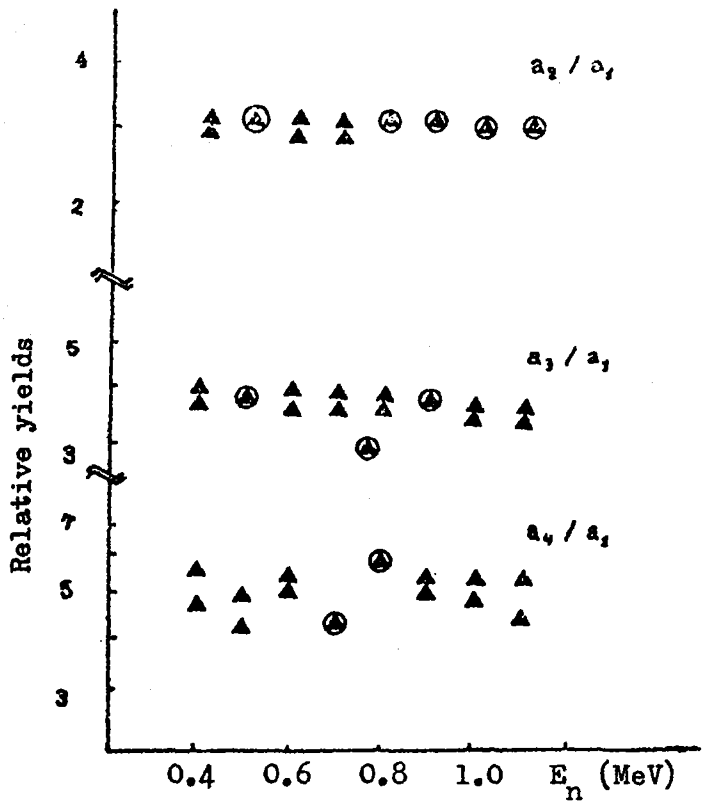

Fig. 1 Relative yields of delayed ^{233}U neutron

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LEVEL DENSITY OF LIGHT EVEN-EVEN NUCLEI WITHIN A WIDE RANGE OF EXCITATION ENERGIES

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The authors consider a description of the available set of experimental data on the level density of light nuclei on the basis of the superfluid-nucleus model. It is shown that the shell structure has a strong influence on the energy dependence of the level density at low excitation energies.

ANALYSIS OF EXPERIMENTAL DATA ON TRANSMISSION FOR ^{238}U WITH A VIEW TO DETERMINING MEAN RESONANCE PARAMETERS

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A comparison is made between experimental and calculated values for the transmission of neutrons in the energy region 0.2-100 keV for uranium samples of different thicknesses and at different temperatures. Estimates of mean resonance parameters - especially force functions - are obtained as a result of statistical processing of the data. The results are interesting from the point of view of more exact fast reactor calculations, in particular as regards the Doppler effect.

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NEUTRON RESONANCE PARAMETERS OF TECHNETIUM-99

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The authors investigate the neutron resonances of the fission fragment nuclide ^{99}Tc in the energy region 20-2100 eV. The neutronoscopic study of this nuclide is of great interest both in nuclear theory and in astrophysics (with regard to the formation of elements in the Universe) [1]. Moreover, the neutron cross-sections of ^{99}Tc have great practical importance in reactor construction. However, information about the neutron resonance parameters of this radionuclide is available only for energies up to ~300 eV [2,3]; moreover, this information is not complete owing to the low resolution of the spectrometers and to the poor statistical accuracy of the measurements.

Measurements of the neutron cross-sections of ^{99}Tc were performed by the time-of-flight method at the I.V. Kurchatov Institute of Atomic Energy, on the 37 m base [4] of the linear accelerator. Measurements were performed of the total cross-section, the radiative capture cross-section and self-induction. The resolution of the spectrometer was 12 ns/m. Two NaI(Tl) crystals (Ø = 200 x 100 mm) were used as detector [4]. The total cross-section was measured by recording the 480-eV photons from a ^{10}B sample (n_3 = 0.024 atom/barn) placed in the detector. The photon energy discrimination level was 1 MeV in the capture cross-section and self-induction measurements, compared with 0.5 MeV in measurements of non-radioactive nuclei. To exclude errors due to the instability of the accelerator power, the measurements were performed in alternating ten-minute series with a ^{99}Tc sample and both with and without a neutron beam.

Three samples 70 mm in diameter and with thicknesses $n_1 = n_2$ = 0.006874 atom/barn and n_3 = 0.002035 atom/barn were prepared from high-purity (99.99%) metallic technetium powder. In the total cross-section measurements, samples with $n_T = n_1 + n_2$ or n_3 were used.

In transmission measurements by the self-indication method, samples with $n_T = n_2$ or n_3 were used, while a sample with $n_D = n_1$ was placed in the detector. The background-to-signal ratio in the measurements of σ_γ is 1:25 for strong resonances. The background associated with the recording of resonance-scattered neutrons did not exceed 1% [5].

The neutron resonance parameters were determined by the combined processing of the results of the transmission, radiative capture and self-induction measurements [6]. The area method was used, with allowance for Doppler broadening and interference between resonance and potential scattering. The neutron and radiation widths of most levels were determined by this method.

In the energy region 20-2100 eV, 101 levels were discovered. The neutron resonance parameters for the first 78 levels (up to 1150 eV) were determined (Table 1). The parameters of the level for $E_0 = 5.6$ eV were taken from Ref. [3]. Values of the radiation width, Γ_γ, were found for 15 strong resonances. The mean value (without allowance for the level for $E_0 = 5.6$ eV) $\bar{\Gamma}_\gamma = 174 \pm 8$ MeV.

A comparison of the parameters of the neutron resonances at energies up to ~300 eV from this work and from Refs [2,3] shows that there is an appreciable level gap in Refs [2,3] and that there are differences between the parameters of the resonances obtained in the different works. Accordingly, the estimated values of the mean parameters of ^{99}Tc presented in Ref. [7] should be changed.

If one plots the dependence of the number of levels on energy, one sees that there is no appreciable level gap at energies up to 490 eV. The mean scattering between levels ($\bar{D}$) calculated for this range is 10.8 ± 1.3 eV. The distributions of the reduced neutron widths and of the distances between levels constructed for this energy range, where 46 levels have been discovered, show that a significant fraction of the levels found (~20) can be ascribed to interaction with a neutron p-wave. Setting aside these p-levels, one obtains $\bar{D}_S = 18.8 \pm 5.0$ eV. It should be noted that this value of the mean distance between S-levels is

~2 times as great as the mean distance $\bar{D}$ between all levels (at energies up to 490 eV). The distribution of the distances between levels is in poor agreement with the corresponding Wigner distribution. Too much importance should not be attached to this, however, since - on the one hand - there is a significant admixture of p-levels and - on the other - the number of merged pairs of levels is (according to the authors' estimates) appreciable (~5). An analysis of the observed ^{99}Tc levels performed with the algorithm employed in Ref. [8] does not reveal any non-random periodicity in their arrangement.

The distribution of the reduced neutron widths was used in determining the S_0 and S_1 strength functions. The S_0 strength function was calculated by determining the mean reduced neutron width with respect to the region $2g\Gamma_n^{(0)} \geq 0.058$ MeV ($2g\Gamma_n^{(0)} = 2.00$ MeV). The S_1 strength function was estimated with respect to the region $2g\Gamma_n^{(0)} < 0.058$ MeV and is $(1.9 \pm 0.7) \times 10^{-4}$. The S_1 strength function is determined mainly by the strong p-levels, which do not enter into the number of weak levels leading to a deviation of the experimental distribution of the reduced neutron widths from the Porter-Thomas distribution [5,9]. The value of the S_1 strength function therefore needs to be determined more exactly. The S_0 strength function was found to be $(0.53^{+0.15}_{-0.10}) \times 10^{-4}$. The error in S_0 is calculated with allowance for the fluctuation of the reduced neutron widths and the distances between levels, starting with the distribution of the force functions and the experimental errors in $2g\Gamma_n^{(0)}$ [10,11]. The force function in Ref. [3] is 0.43×10^{-4}, which is less than the value obtained by the authors of this paper. This is because some levels are missing at energies up to ~300 eV. It should be noted that S_0 as calculated from these authors' data with allowance for all levels at energies up to 1150 eV is 0.56×10^{-4}.

The value $S_0 = (0.53 {+0.15 \atop -0.10}) \times 10^{-4}$ does not agree with calculations based on the optical model. Adopting the shell approach to the theory of nuclear reactions [12,13], the authors of Ref. [14] showed that the optical model did not describe the experimental dependence of force functions on atomic weight in a region of minima. Calculations of the S_0 strength function within the framework of this approach give a value of 0.55×10^{-4} for ^{99}Tc [15]; the generally accpeted forms and parameters of the potentials were used and the values of the spectroscopic factors (occupation numbers) for 3_S states were taken into account.

Table 1

Results of ^{99}Tc measurements

	E_0 (eV)	ΔE (eV)	$2g\Gamma_n^{(0)}$ (MeV)	$\Delta(2g\Gamma_n^{(0)})$ (MeV)	Γ_γ (MeV)	$\Delta\Gamma_\gamma$ (MeV)
I	5,6	-	I,84	0,I5	I34	4
2	2I,I0	0,02	I,6I	0,26	I50	30
3	39,75	0,05	0,22	0,02	I70	30
4	56,62	0,08	0,60	0,0I	I50	30
5	6I,40	0,09	0,009	0,002		
6	67,53	0,I0	0,0I0	0,002		
7	80,96	0,I3	0,0I4	0,006		
8	8I,65	0,I	0,020	0,004		
9	III,I	0,2	I,33	0,09	I70	80
I0	II4,I	0,2	0,005	0,00I		
II	I23,9	0,3	0,45	0,04	I40	50
I2	I26,8	0,3	0,0I2	0,003		
I3	I48,2	0,3	0,00I8	0,0008		
I4	I63,2	0,4	6,7	0,5	I60	40
I5	I73,I	0,4	0,023	0,007		
I6	I82,5	0,4	5,6	0,6	I90	80
I7	I92,I	0,5	4,2	0,3	I80	20
I8	I96,7	0,5	0,026	0,007		
I9	206,9	0,5	0,046	0,0I5		
20	2I0,4	0,6	0,05I	0,0I5		
2I	2I5,0	0,6	0,06	0,02		
22	22I,I	0,6	0,046	0,02		
23	226,2	0,7	0,0I9	0,009		
24	24I,7	0,7	3,09	0,25	200	40
25	262,8	0,8	0,0I7	0,006		
26	273,5	0,8	0,053	0,02		
27	280,5	0.9	I,0I	0,02	I70	25
28	30I,0	0,9	2,42	0,25		
29	308,0	I,0	I,37	0,I	I60	80
30	3I8,5	I,I	0,058	0,02		
3I	326,I	I,I	0,03	0,0I		
32	333,9	I,I	0,0I6	0,005		
33	344,6	I,2	0,I0	0,03		
34	35I,9	I,2	0,06	0,02		
35	359,5	I,3	0,83	0,03		
36	366,0	I,3	9,4	I,5		
37	38I,0	I,4	I,7	0,I	I90	50
38	388,I	I,4	0,05	0,02		
39	399,9	I,5	0,040	0,0I5		
40	4I8,6	I,6	3,8	0,3	200	40
4I	428,4	I,8	4,9	0,4	240	50
42	440,4	I,7	0,080	0,00I		
43	449,2	I,8	0,I3	0,03		
44	462,0	I,9	2,42	0,I4		
45	48I,3	2,0	I,22	0,09		
46	489,4	2,0	0,26	0,03		
47	5I0,4	2,2	0,03	0,0I		
48	52I,5	2,2	I,2I	0,I3		
49	523,7	2,3	I,29	0,I3		
50	530,6	2,3	0,06	0,03		
5I	539,9	2,4	I,50	0,17		
52	566,9	2,5	0,55	0,I3		
53	60I,4	2,8	2,20	0,I6		

Table 1, continued

	E_0 (eV)	ΔE (eV)	$2g\,\Gamma_n^{(0)}$ (MeV)	$\Delta(2g\,\Gamma_n^{(0)})$ (MeV)	Γ_γ (MeV)	$\Delta\Gamma_\gamma$ (MeV)
54	609,8	2,8	I,70	0,24		
55	627,2	3,0	0,40	0,06		
56	636,2	3,0	0,II	0,04		
57	657,9	3,2	2,I8	0,3I		
58	677,4	3,3	I,38	0,23		
59	690,9	3,4	0,36	0,07		
60	708,3	3,6	0,06	0,02		
61	730,I	3,7	0,44	0,15		
62	749,I	3,8	4,75	I,I0	I80	30
63	756,9	3,9	2,40	0,29		
64	772,8	4,0	0,29	0,II		
65	8I0,5	4,3	I,48	0,28		
66	8I9,3	4,4	I,I9	0,2I		
67	846,5	4,6	4,8I	I,37		
68	85I,I	4,8	4,80	I,37		
69	879,9	4,9	I,00	0,27		
70	899,9	5,I	7,0	I,0		
71	936,6	5,4	0,I2	0,04		
72	98I,3	5,8	0,32	0,I9		
73	I004	6	I,39	0,3I		
74	I029	6	0,8I	0,3I		
75	I054	6	I,66	0,3I		
76	I08I	7	6,I	2,4		
77	I094	7	6,I	2,4		
78	III5	7	0,3	0,2		
79	II44	7	3,6	I,5		

From 1150 eV to 2110 eV the following resonances of ^{99}Tc were found at the energies (eV):

I.	II89 ± 7	9.	I4I8 ± I0	I7.	I805 ± I4
2.	I2I2 ± 8	I0.	I459 ± I0	I8.	I834 ± I5
3.	I228 ± 8	II.	I49I ± II	I9.	I879 ± I5
4.	I278 ± 8	I2.	I570 ± II	20.	I942 ± I6
5.	I296 ± 9	I3.	I606 ± I2	2I.	I975 ± I6
6.	I3I4 ± 9	I4.	I668 ± I3	22.	2025 ± I7
7.	I34I ± 9	I5.	I72I ± I3	23.	2I04 ± I8
8.	I379 ± 9	I6.	I776 ± I4		

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FISSION OF ^{227}Ac BY DEUTERONS

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(Article submitted to Yad. Fiz.)

The authors' aim was to study ^{227}Ac fission by deuterons with E_d = 4–6.8 MeV, and their work represents the first experiment relating to this phenomenon. They measured the fission cross-sections and, for a deuteron energy E_d = 6.8 MeV, determined the fission yield in the symmetrical fission peak region and the anisotropy of the dispersion of the fission fragments. The fission fragments were recorded in the course of the fission cross-section measurements by means of mica-based track detectors treated by a well-known technique [1]. Fission fragment spectrometry was carried out using glass-based solid track detectors with filters [2]. The actinium target (weight 0.84 μg) was prepared by vacuum evaporation.

The effective fissionability of the resulting compound nucleus of ^{229}Th was determined on the basis of the measured fission cross-sections (Table 1): $W_{f\ eff}(^{229}Th) = 0.25 \pm 0.04$. This value does not depend on the excitation energy of the ^{229}Th nucleus in the energy range studied.

The anisotropy $\frac{\sigma_f(0°)}{\sigma_f(90°)}$ was found to be 1.20 ± 0.05.

The contribution of the symmetric fission peak neutrons is 27 ± 7% and is the same for both 90° and 170° to the direction of the deuteron beam. Previously, the contribution of the symmetric fission peak fragments of the ^{229}Th nucleus had been determined only for comparatively high excitation energies ($E_{excit} \approx 30$ MeV) in an experiment involving the bombardment of ^{226}Ra by ^{3}He ions [3].

Table 1

E_d (MeV)	6.8	6.1	5.3	4.0
σ_f (cm^2)	$(1.5 \pm 0.2)10^{-28}$	$(1.34 \pm 0.16)10^{-29}$	$(8 \pm 1)10^{-31}$	$(1.3 \pm 0.6)10^{-32}$

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INELASTIC SCATTERING OF 4.75-MeV NEUTRONS IN COPPER

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The spectrum of inelastically scattered neutrons was measured at the Radium Institute by means of a time-of-flight spectrometer in conjunction with an electrostatic generator operating in a pulse regime. The ion source of the spectrometer gives off ion pulses with a duration of about 25 ns which are compressed by an alternating electric field to 2 ns at the target. The pulse recurrence frequency is 2 MHz. The current strength in the pulse is about 0.5 mA.

Cylindrical stilbene crystals 50 mm in diameter and height together with FEU-30 photomultipliers were used for neutron recording. By means of the pulse shape selection circuit it was possible to reduce the background to on average about 20% of the useful counting efficiency. The time-of-flight base was 290 cm. A cylinder 40 mm in diameter and 50 mm high made of copper of natural isotopic composition was used as scatterer. The entire neutron-recording system was placed inside a 100 x 150 cm block of paraffin with boron carbide capable of being moved for the measurement of scattering through different angles. Additional shielding (also of paraffin with boron carbide) in the form of a cylinder with a central aperture was placed between the scattered-neutron source and the main shielding. The moment of arrival of the ion pulse at the target was registered by a capacitative transducer. A time-to-amplitude converter and an AI-1024 multichannel analyser were used for measuring the time of flight. Standard targets of titanium 1 mg/cm^2 thick and saturated with deuterium were used as neutron sources.

Energy calibration of the set-up was carried out with neutrons from spontaneous ^{252}Cf fission, the spectrum shape of which was taken to be of the form $N(E) = N_0 \exp(-0.88E) \sin h(\sqrt{2E})$ [1].

The spectra of the neutrons inelastically scattered in the copper were measured at an angle of 82°. The width of the elastic-scattering peak at half-height was 6 ns. More than half of this value was due to the geometric dimensions of the scatterer and the stilbene crystal and to slowing-down of the deuterons in the target. For the cross-section of the inelastically scattered 4.75-MeV neutrons, the authors used data from Ref. [2], according to which their experimental conditions corresponded to a value of 68 mbarn. The cross-sections of inelastically scattered neutrons for a number of energy ranges are presented below:

Energy range (MeV)	Elastic E_0 = 4.75	3.8 - 3.07	3.07 - 2.33	2.33 - 1.6	1.6 - 0.9
Cross-section (mb)	68	20.2 ± 1.5	13.3 ± 0.8	9.7 ± 0.5	4.4 ± 0.4

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GAMMA RAYS FROM THE REACTION $^{96,98,100,102,104}Ru(n,\gamma)$ $^{97,99,101,103,105}Ru$ INDUCED BY THERMAL NEUTRONS

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A.F. Ogorodnik, M.M. Tuchinsky

The spectra of gamma rays emitted by odd ruthenium isotopes resulting from thermal-neutron capture by $^{96,98,100,102,104}Ru$ nuclei were measured using a spectrometer with a Ge(Li) detector in the horizontal channel of the WWR-M reactor of the Nuclear Research Institute of the Academy of Sciences of the Ukrainian SSR. The characteristics of the ruthenium samples enriched in the corresponding isotopes are presented in Table 1. The thermal-neutron flux at the sample location was 6.5×10^7 neutrons/cm^2·s.

The measurements were performed in the gamma energy range 2-8 MeV. The calibration of the spectrometer and the treatment of the measured spectra by means of a BESM-4 computer are described in Ref. [1]. The following results were obtained. Capture gamma rays of ^{97}Ru and ^{99}Ru were not detected. In the case of ^{99}Ru, this may be due to insufficient enrichment of the sample. Data on the gamma rays of $^{101,103,105}Ru$ are presented in Tables 2-4. Using their own results, data obtained with samples consisting of a natural mixture of ruthenium isotopes [2] and information about lower levels from works on radioactive decay [3] and nuclear reactions [4-6], the authors constructed decay schemes for these isotopes. The mean binding energies of the last neutron in each nucleus was determined from the total energies of the cascade transitions. They were found to be:

$E_{bind} = 6.8009 \pm 0.0033$ MeV for ^{101}Ru;

$E_{bind} = 6.2754 \pm 0.0035$ MeV for ^{103}Ru;

$E_{bind} = 5.9745 \pm 0.0026$ MeV for ^{105}Ru.

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Table 1

Characteristics of samples enriched in ruthenium isotopes (weight, percentage concentration, activation cross-section) and investigated by means of the reaction (n,γ)

Enriched in	Weight (g)	96	98	99	100	101	102	104
^{96}Ru	0,5976	93,9	0,4	I,8	0,8	0,9	I,5	0,7
^{98}Ru	0,5995	I,6	6I,6	2I,9	6,2	3,7	4,0	I,6
^{100}Ru	2,0252	0,I	0,I	3,6	93,0	I,9	I,I	0,4
^{102}Ru	I,98I3	0,I	0,I	0,I	0,I	0,4	99,2	0,4
^{104}Ru	I,9943	0,I	0,I	0,I	0,I	0,2	I,2	98,5
		0,2I	-	I0,6/6/I0,4		3,I	I,44	0,7

Table 2

$^{100}Ru(n,\gamma)^{101}Ru$

Gamma line No.	E_γ(MeV)	I_γ (rel.)	Gamma line No.	E_γ(MeV)	I_γ (rel.)
I	6,683I/29/	I0/2/	8	4,8392/23/	I3/3/
2	6,6083/34/	I6/4/	9	4,8082/I8/	I8/3/
3	6,27I4/I5/	I00/5/	I0	4,7I76/I3/	44/8/
4	6,2482/27/	22/3/	II	4,6203/I3/*	24/4/
5	6,0927/4I/	I3/3/	I2	4,483I/I2/	59/6/
6	5,3063/II/	63/4/	I3	4,2445/33/	40/20/
7	5,2799/2I/	20/3/	I4	4,I439/I5/	32/9/

*Gamma rays possibly belonging to ^{103}Ru.

Table 3

$^{102}Ru(n,\gamma)^{103}Ru$

Gamma line No.	E_γ(MeV)	I_γ(rel.)	Gamma line No.	E_γ(MeV)	I_γ(rel.)
I	5,6673/I9/	30/3/	I2	4,3285/I2/	40/4/
2	5,0310/39/	7/2/	I3	4,2665/I0/	I00/I0/
3	4,8897/20/	I7/3/	I4	4,2215/22/	32/7/
4	4,8293/29/	20/6/	I5	4,I6I7/I3/	I2/2/
5	4,7932/34/	I5/5/	I6	4,0640/I6/	20/4/
6	4,7414/2I/	20/4/	I7	4,0210/I5/	73/9/
7	4,6258/II/	96/I0/	I8	4,002I/23/	43/9/
8	4,5062/20/	5I/7/	I9	3,9473/7/	28/3/
9	4,4363/58/	I6/6/	20	3,6777/68/	24/7/
I0	4,3966/I2/	26/3/	2I	3,6528/20/	64/12/
II	4,35I3/8/	63/4/			

Table 4

$^{104}Ru(n,\gamma)^{105}Ru$

Gamma line No.	E_γ(MeV)	I_γ(rel.)	Gamma line No.	E_γ(MeV)	I_γ(rel.)
I	5,9105/I9/	28/2/	9	5,I27I/II/	23/2/
2	5,8893/42/	9/3/	I0	5,I079/20/	9/I/
3	5,7873/35/	3/I/	II	5,0226/I0/	I00/6/
4	5,75I4/I4/	I7/I/	I2	4,585I/I0/	I0/2/
5	5,5864/I4/	34/3/	I3	3,7604/I5/	I4/3/
6	5,528I/38/	4/2/	I4	3,5052/I7/	32/4/
7	5,4436/I3/	I5/I/	I5	3,47I9/II/	54/5/
8	5,4I47/37/	3/I/			

GAMMA RAYS FROM THE REACTION $^{104,106,108}Pd(n,\gamma)$ $^{105,107,109}Pd$ INDUCED BY THERMAL NEUTRONS

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A.F. Ogorodnik, M.M. Tuchinsky

The spectra of gamma rays produced by the capture of thermal neutrons by even isotopes of palladium were measured using a spectrometer with a Ge(Li) detector in the horizontal channel of the Nuclear Research Institute's WWR-M reactor.

The measurement techniques and the methods for processing the results were the same as those employed in Ref. [1]. The characteristics of samples enriched in the corresponding isotopes are presented in Table 1.

The following results were obtained in measuring gamma spectra in the energy range 2-8 MeV: the reaction $^{104}Pd(n,\gamma)^{105}Pd$ gave very weak gamma rays, energies and relative intensities (see Table 2); no gamma rays were detected in the reaction $^{106}Pd(n,\gamma)^{107}Pd$; in the reaction $^{108}Pd(n,\gamma)^{109}Pd$, 29 gamma rays ascribed to ^{109}Pd were identified in the energy range 3.5-6.0 MeV. The energies and relative intensities are given in Table 3.

The authors propose a decay scheme of the ^{109}Pd nucleus on the basis of their own measurements and of published data relating to levels of the ^{109}Pd nucleus from (d,p) and (d,t) reactions [2,3] and to gamma rays resulting from capture by a natural mixture of palladium isotopes [4].

The mean binding energy of the last neutron in ^{109}Pd, calculated from the sums of the cascade transition energies, was found to be:

$$E_{cb} = 6.1533 \pm 0.0019 \text{ MeV}$$

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Table 1

Characteristics of samples enriched in palladium isotopes and investigated by means of the reaction (n,γ)

Enriched in	Weight (g)	102 (%)	104 (%)	105 (%)	106 (%)	108 (%)	110 (%)
^{104}Pd	1,9943	0,1	90,0	7,6	2,0	0,4	0,1
^{106}Pd	0,5734	0,1	5,2	9,1	78,8	3,6	3,3
^{108}Pd	2,7498	0,1	0,1	0,3	0,9	98,4	0,4
σ barn		4,8/15/	-	-	0,292/29/-		-

Table 2

$^{104}Pd(n,\gamma)^{105}Pd$

Gamma line No.	E_γ (MeV)	I_γ (rel.)
1	6,652/8/	77/20/
2	6,615/5/	100/25/
3	5,9170/26/	45/9/
4	5,526/3/	64/14/
5	5,1847/15/	89/11/

Table 3

Gamma line No.	E_γ (MeV)	I_γ (rel.)	Gamma line No.	E_γ (MeV)	I_γ (rel.)
1	5,8840/20/	6/1/	16	4,5450/20/	7/1/
2	5,8270/15/	20/2/	17	4,5124/8/	12/1/
3	5,7204/10/	23/1/	18	4,4450/20/	10/2/
4	5,6996/26/	5/1/	19	4,4248/23/	10/2/
5	5,4800/10/	15/1/	20	4,3588/10/	13/1/
6	5,4564/46/	3/1/	21	4,3155/19/	16/2/
7	5,4308/9/	16/1/	22	4,2371/10/	18/1/
8	5,3997/36/	2/1/	23	4,0682/17/	41/2/
9	5,2129/5/	31/1/	24	4,0367/16/	13/2/
10	5,1870/14/	6/1/	25	3,9260/21/	11/2/
11	5,0130/12/doubl.	14/3/	26	3,9102/23/	10/2/
12	4,7946/5/	100/3/	27	3,7427/16/	22/3/
13	4,7594/9/	41/2/	28	3,6909/18/	23/3/
14	4,6752/9/	11/2/	29	3,6738/36/	25/3/
15	4,6182/21/	4/1/			

GAMMA RAYS FROM THE REACTION $^{186,187}Os(n,\gamma)$ $^{187,188}Os$ INDUCED BY THERMAL NEUTRONS

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The spectra of gamma rays produced by the capture of thermal neutrons by $^{186,187}Os$ nuclei were measured in the horizontal channel of the Nuclear Research Institute's WWR-M reactor using a spectrometer with a Ge(Li) detector. The experimental techniques and the processing of the results are described in Ref. [1]. The composition of the sample enriched in ^{186}Os is shown in Table 1. The sample weight was 0.394 g and the capture cross-sections of the osmium isotopes were taken from Ref. [2]. The second sample was enriched to more than 99.5% in ^{187}Os and weighed 0.0938 g. In the first sample, the ^{187}Os contribution was comparable with the ^{186}Os contribution. Consequently, it was possible to identify in the spectrum only a few gamma lines belonging to ^{187}Os (Table 2). All the gamma rays detected in the reaction $^{187}Os(n,\gamma)^{188}Os$ are ascribed to the ^{188}Os (Table 3).

The authors construct ^{187}Os and ^{188}Os decay schemes on the basis of their own measurement results, of data taken from Ref. [3] (the work described in which was done with a sample consisting of a natural mixture of osmium isotopes), and of the results of work on the radioactive decay of ^{187}Ir [4], ^{188}Ir and ^{188}Re [5]. The mean binding energies of the last neutron in these isotopes are found from the total cascade transition energies. For ^{187}Os it was found to be $E_{cb} = 6.2952 \pm 0.0018$ MeV; for ^{188}Os, the binding energy calculated in this way ($E_{cb} = 7.9886 \pm 0.0029$ MeV) coincided with the measured energy of the direct transition to the ground state ($E = 7.9887 \pm 0.0012$ MeV).

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Table 1

Isotopic composition of sample enriched in ^{186}Os

Isotope	^{184}Os	^{186}Os	^{187}Os	^{188}Os	^{189}Os	^{190}Os	^{192}Os
Concentration (%)	0.05	42.1	9.6	17.9	9.2	10.5	10.7
Capture cross-section (barn)	-	80/13/	320/10/	-	61/16/	16/5/	11/2/

Table 2

$^{186}Os(n,\gamma)^{187}Os$

Gamma line No.	E_γ (MeV)	Emitting isotope	I_γ (rel.)
I	7,8344/5/	I88	I7/I/
2	7,3637/I2/	I88	I2/I/
3	6,7259/I9/	?	9/I/
4	6,5I33/I8/	I88	9/I/
5	6,2889/2I/	I87	9/2/
6	6,2I92/10/	I87	I00/2/
7	6,I936/I4/	I87	27/2/
8	5,9220/I3/	I88	26/2/
9	5,887I/24/	-	10/2/
I0	5,792I/I3/	I87	23/2/
II	5,7005/I3/	I88	50/4/
I2	5,5708/I4/	I86	55/4/
I3	5,5533/3I/	-	I5/4/
I4	5,3578/I4/	-	27/3/
I5	5,I739/I3/	I87	43/3/
I6	5,I427/16/	-	26/2/
I7	5,I026/I9/	I88	22/3/
I8	5,0789/48/	I87?	I9/3/
I9	5,0I77/I3/	I87?	22/2/
20	4,959I/I9/	I88	I2/2/
2I	4,9I27/I5/	I88	28/2/
22	4,84I5/26/	I88	27/4/
23	4,8I36/I3/	I88	99/5/
24	4,7463/I4/	I88	50/4/
25	4,5557/5/	I87	79/7/
26	4,2926/I4/	-	42/I4/

Table 3

$^{187}Os(n,\gamma)^{188}Os$

Gamma line No.	E_γ (MeV)	I_γ (rel.)	Gamma line No.	E_γ (MeV)	I_γ (rel.)
I	7,9887/I2/	0,07/I/	I9	5,4666/27/	0,05/I/
2	7,8344/5/	0,I5/I/	20	5,3647/I3/	0,I0/I/
3	7,3597/I0/	0,08/I/	2I	5,3325/18/	0,07/I/
4	6,9029/25/	0,02/I/	22	5,2842/22/	0,03/I/
5	6,5I72/I7/	0,05/I/	23	5,249I/I4/	0,09/I/
6	6,3737/I9/	0,02/I/	24	5,2262/I7/	0,07/I/
7	6,I847/I2/	0,04/I/	25	5,I7I8/25/	0,09/I/
8	6,1497/I2/	0,05/I/	26	5,I2I0/27/	0,I0/I/
9	6,03I0/I2/	0,07/I/	27	5,I006/I7/	0,20/2/
I0	5,9676/38/	0,02/I/	28	4,9860/33/	0,03/I/
II	5,92I9/9/	0,I2/I/	29	4,9628/I4/	0,II/I/
I2	5,7365/36/	0,03/I/	30	4,9I7I/27/	0,09/I/
I3	5,7027/7/	0,I9/I/	3I	4,8477/I3/	0,09/I/
I4	5,6427/25/	0,07/I/	32	4,8I28/5/	0,40/I/
I5	5,6203/36/	0,05/I/	33	4,75I4/2I/	0,I3/2/
I6	5,5745/9/	0,22/I/	34	4,7II6/28/	0,I0/2/
I7	5,54I2/I6/	0,03/2/	35	4,6749/I9/	0,07/I/
I8	5,4860/I6/	0,08/I/			

STUDY OF THE INTERACTION OF SLOW NEUTRONS WITH $^{190,192,194,196,198}Pt$

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(Article submitted to Conference on Neutron Physics, Kiev, 1973, and to Yad. Fiz.)

Using the time-of-flight method and the Nuclear Research Institute's WWR-M reactor, the authors obtained information about the neutron resonances of the isotopes $^{190,192,194,196,198}Pt$ in the energy region 0-2000 eV. Above 3 eV the resolution was 55 ns/m; below 3 eV it was 1.8 μs/m. The purpose of the measurements was to study the isotopic dependence of the level density, the potential scattering amplitudes, the strength function and the partial cross-sections for thermal neutrons.

The resonances of the platinum isotopes are presented in Table 1. The experimental results were processed on a BESM-4 computer using programs developed by V.A. Pshenichny and V.K. Rudishin.

Values of the mean distances between levels and of the distances reduced to an excitation energy of 6.5 MeV for $^{192,194,196,198}Pt$ are given in Table 2, from which it can be seen that the distance is least in the case of the isotope with 114 neutrons. The observed isotopic dependence confirms the authors' belief that the level density is at a maximum when N = 112-114.

The strength functions were determined by the least-squares method from the resonance parameters and the slope of the averaged cross-section in the energy range 5-50 keV. The strength function values (Table 3) do not contradict Jain (Nucl. Phys. 50 (1964) 157) as regards the optical model of deformed nuclei, according to which in the 190-200 keV region there is a rapid change in the strength function from 4×10^{-4} to 1.5×10^{-4}.

Knowing the resonance parameters in a wide energy range it was possible to determine the potential scattering from the cross-section between resonances. The data obtained are in good agreement with the values of the cross-section for scattering in the thermal region if one takes into account the contribution of resonances. The experimental values of the potential scattering amplitudes R' for all platinum isotopes are higher than those calculated by Jain and are constant within the error limits (with account taken of the R' fluctuations of the neutron widths). The levels indicated for R' correspond to possible contributions of unknown positive and negative levels, the statistical error being much less than these levels - except for ^{192}Pt, where the statistical error is greater.

An attempt was made to study the interaction of neutrons with ^{190}Pt using a sample in which the concentration of this isotope was 0.8%. Only one level was detected (see Table 1).

The total cross-sections of the platinum isotopes in the thermal region are subject to the law $\sigma_{tot} = \sigma_p + \sigma_a \frac{V_o}{V}$, where σ_p is the scattering cross-section, σ_a is the capture cross-section for $V_o = 2200$ m/s and V is the neutron velocity (see Table 4). Analysis of the data was carried out by the least-squares method. The capture cross-section values for the platinum isotopes were very exact compared with the available measurement results.

The high capture value and the low Γ^o value for the ^{190}Pt level detected point to a high level density in the case of this isotope and to the probable presence of a level near the threshold.

Table 1

Resonances of $^{190,192,194,196,198}Pt$

E (eV)	Γ_n^0 (MeV)	E (eV)	Γ_n^0 (MeV)
Pt I90			
27,60±0,05	I,2±0,6	704 ± I5	32 ± 7
Pt I92		880 ± 20	27 ± 4
2I,65±0,05	0,28±0,03	II95 ± 30	66 ± I0
46,55±0,I5	6,2 ±0,9	2450 ± 80	-
53,88±0,20	2,02±0,50		
58,56±0,20	0,I2±0,05	Pt I96	
I29,9± 0,7	I5,2±I,5		
I48,0±0,9	2I,0±2,5	I6,90±0,05	0,007±0,002
I77,6±2	I0,5±5	306±4	8,5±0,6
338 ±5	-	576±I2	4,4±2,0
366 ±6	-	I7I0±50	I50±50
897 ±20		2450±80	-
Pt I94		Pt I98	
370 ±5	7,6±2,0	96,I±0,5	8 ± I
600 ±I2	49±I0	704 ± I5	78 ± I0
		840 ± 20	2I ± 3
		I340 ± 35	I30 ± 50

Table 1a

Low-lying resonances of ^{195}Pt

E (eV)	Γ_n^0 (MeV)	Γ (MeV)	E (eV)
II,90±0,0I*	3,2±0,2	I50±I5	II9,5±I,0*
I9,38±0,0I*	I,4±0,07	200±25	I39,5±I,3
67,3 ±0,4**	-	-	I50,9±I,4**
III,7±0,9	-	-	

*The parameter values and accuracies result from measurements on all samples.

**In accordance with BNL-325, 2nd Ed., Suppl. No. 2, these levels are combined ones; their parameters are reflected in all the observed transmissions.

Table 2

Distances between levels of platinum isotopes

Isotope	$\bar{D}$ (eV)	D_o (eV)
Pt 192	12 ± 4	16,5
Pt 194	270 ± 75	310
Pt 196	380 ± 100	280
Pt 198	340 ± 70	160

Table 3

Strength functions S and potential scattering amplitudes R' for platinum isotopes

Isotope	S (104)		R' (Fermi)
	on basis of resonances	on basis of slope of cross-section	
Pt 192	3,6 ± 0,7	-	10,5 ± 1,0
Pt 194	1,5 ± 0,5	1,3 ± 0,1	$10,5^{+0,3}_{-0,45}$
Pt 195	-	1,0 ± 0,2	$10,4^{+0,4}_{-0,3}$
Pt 196	1,1 ± 0,6	0,8 ± 0,4	$10,1^{+0,8}_{-0,4}$
Pt 198	1,8 ± 0,6	1,3 ± 0,4	$9,5^{+1,0}_{-0,5}$

Table 4

Scattering and capture cross-sections of platinum isotopes in the thermal-neutron region

Isotope	σ_p (barn)	σ_a (barn) for V_o = 2200 m/s
Pt 190	10	800 ± 70
Pt 192	12,3 ± 1,2	10 ± 2,5
Pt 194	11,0 ± 0,2	1,2 ± 0,4
Pt 195	10,1 ± 0,2	30 ± 1,2
Pt 196	12,3 ± 0,2	0,3 ± 0,2
Pt 198	7,7 ± 0,2	4,2 ± 0,3

TOTAL NEUTRON CROSS-SECTIONS OF $^{174,176,177,178,179,180}Hf$ IN THE NEUTRON ENERGY RANGE 0.06-0.5 eV

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Total neutron cross-sections of $^{174,176,177,178,179,180}Hf$ as a function of neutron energy in the range 0.02-0.5 eV were measured by the time-of-flight method in the Nuclear Research Institute's WWR-M reactor. The samples were in the form of HfO_2. The concentration of the chemical impurities in the samples was such that their total contribution to the sample cross-section did not exceed 0.01 barn. The transmissions of the samples were measured by the time-of-flight method with a resolution of 1.7 μs/m. The time for one measurement with and without sample was determined by a specific number of neutron pulses (3×10^5). Information about sample enrichment and thickness is given in Table 1. The energy dependence of the total neutron cross-sections of $^{174,176,177,178,179,180}Hf$ in the energy range 0.5-0.06 eV, where the cross-section is subject to the 1/v law, is expressed by a formula of the type

$$\sigma_{tot} = \sigma_s + \sigma\sqrt{\frac{0.0253}{E}}$$

derived by the least-squares method; here σ_{tot} is the total cross-section in barns, σ_s coincides with the scattering cross-section and is defined as σ_{tot} for $E \to \infty$, and σ_a is the absorption cross-section for v = 2200 m/s.

Below 0.02 eV the authors observe a departure from the 1/v law, which they associate with the shadow scattering of neutrons on grains at small angles.

Table 2 gives the total neutron cross-sections, the absorption cross-sections for v = 2200 m/s and the scattering cross-sections obtained from the experimental results by a least-squares treatment; the scattering cross-section of ^{174}Hf was measured directly at the authors' laboratory in a 4π geometry by N.L. Gnidak.

Owing to the adjacent ^{177}Hf levels with energies of 1.09 eV and 2.08 eV, the total cross-section of ^{177}Hf does not obey the 1/v law.

The total neutron cross-sections of $^{174,176,177,178,179}Hf$ as a function of neutron energy are presented in Table 3, in which the statistical errors are also indicated. The upper limit of the error due to uncertainty as regards the concentration of ^{174}Hf in the samples of ^{178}Hf, ^{179}Hf and ^{180}Hf is less than 1% and lies within the limits of the statistical accuracy.

Table 1

Characteristics of samples of hafnium isotopes

Sample	ISOTOPE											
	I74		I76		I77		I78		I79		I80	
	P%	n (10^{20})	P%	n (10^{20})	P%	n (10^{20})	P%	n (10^{20})	P%	n (10^{20})	P%	n (10^{20})
I74	I3,0	7,5246	9,7	5,6493	20,2	II,6921	23,7	I3,7180	I0,2	5,9039	23,2	I3,4286
I76	<0,05	-	68,9	69,5579	I9,5	I9,6862	6,I	6,I582	I,8	I,8I72	3,7	3,7353
I77	0,I	0,0147	I,I	0,I615	89,0	I3,0639	6,5	0,9541	I,5	0,2202	I,9	0,2789
I78	<0,I	-	0,2	0,2094	I,3	I,36I5	95,3	99,8074	I,6	I,6757	I,6	I,6757
I79	<0,05	-	0,4	0,5474	I,8	2,4635	3,0	4,I058	80,9	II0,7188	I3,9	I9,0234
I80	<0,I	-	0,I	-	0,4	0,5550	I,0	I,3875	I,4	I,9425	97,2	I34,8645

P - percentage concentration of isotope in sample
n - number of nuclei of isotope in sample per cm^2

Table 2

Neutron cross-sections of hafnium isotopes calculated from experimental data for $v = 2200$ m/s

Hafnium isotope	Total cross-section σ_{tot} (barn)	Absorption cross-section σ_a (barn)	Scattering cross-section $\sigma_s = \sigma_{tot}$ ($E \to \infty$)
I74	650 ± 50	635 ± 50	I5 ± 3[x]
I76	I9 ± I5	I6 ± I5	3 ± 4
I77	380 ± I0	-	-
I78	99 ± 4	94 ± 4	5,4 ± I,2
I79	65 ± 2,5	58 ± 2	6,7 ± I
I80	5I ± 4	29 ± 3	22 ± 1

[x] Scattering cross-section obtained by direct measurements in a 4π geometry.

Table 3

Energy dependence of total neutron cross-sections of hafnium isotopes

Neutron energy (eV)	Total cross-sections (barn)					
	Hafnium 174	Hafnium 176	Hafnium 177	Hafnium 178	Hafnium 179	Hafnium 180
I	2	3	4	5	6	7
0,50	I05 ± I5	8 ± 3	206 ± 4	27 ± I	I8 ± I	29,4±0,5
0,45	II5 ± I5	8 ± 3	I97 ± 4	28 ± I	2I ± I	29,3±0,5
0,40	I25 ± I5	I0 ± 3	I78 ± 4	29 ± I	2I ± I	29,7±0,5
0,35	I57 ± I5	I0 ± 3	I73 ± 4	3I ± I	22 ± I	29,9±0,5
0,30	I65 ± I5	II ± 3	I7I ± 4	33 ± I	24 ± I	30,5±0,5
0,25	I78 ± I5	9 ± 3	I69 ± 4	35 ± I	25 ± I	31,5±0,5
0,20	205 ± I5	6 ± 3	I76 ± 4	39 ± I	27 ± I	32,4±0,5
0,I9	225 ± I5	8 ± 3	I75 ± 4	40 ± I	28 ± I	33,1±0,5
0,I8	230 ± I0	II ± 3	I78 ± 4	4I ± I	29 ± I	32,7±0,5
0,I7	23I ± I0	II ± 2	I8I ± 4	42 ± I	29 ± I	33,3±0,5
0,I6	232 ± I0	7 ± 2	I93 ± 3	43 ± I	29 ± I	33,3±0,5

Table 3 (continued)

Neutron energy (eV)	Total cross-sections (barn)					
	Hafnium 174	Hafnium 176	Hafnium 177	Hafnium 178	Hafnium 179	Hafnium 180
0,I5	253±I0	9 ± 2	I85 ± 3	44±I	30,1±0,5	33,1±0,5
0,I4	260±I0	9 ± 2	I9I ± 3	45±I	3I,1±0,5	34,2±0,5
0,I3	268±8	II ± 2	I94 ± 3	46±I	32,2±0,5	35,5±0,5
0,I2	287±8	II ± 2	200 ± 2	48±I	32,0±0,5	36,0±0,5
0,II	304±8	I3 ± 2	202 ± 2	50±I	34,7±0,5	36,0±0,5
0,I0	308±8	I2 ± 2	2I2 ± 2	52±I	35,6±0,5	36,7±0,5
0,09	332±8	I3 ± 2	220 ± 2	55±I	37,3±0,5	37,7±0,5
0,085	335±8	II ± 2	229 ± 2	56±I	38,0±0,5	38,0±0,5
0,080	348±8	I4 ± 2	232 ± 3	58±I	39,2±0,5	38,3±0,5
0,075	360±8	I3 ± 2	239 ± 3	60±I	40,3±0,5	39.0±0,5
0,070	376±8	I4 ± 2	245 ± 3	62±I	41,7±0,5	40,0±0,5
0,065	398±8	I6 ± 2	249 ± 3	64±I	43,0±0,5	40,6±0,5
0,060	4I6±8	I4 ± 2	259 ± 3	68±I	44,6±0,5	42,0±0,5
0,055	427±I0		272 ± 3			
0,050	467±I0		28I ± 3			
0,045	483±I0		292 ± 3			
0,040	520±I0		309 ± 3			
0,035	553±I0		328 ± 3			
0,030	604±I5		348 ± 3			
0,0253	650±I5		38I ± 3			
0,020	750±20		433 ± 5			

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CROSS-SECTION AND ANISOTROPY OF ^{235}U PHOTOFISSION

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The authors studied the intermediate structure of the fission cross-section $\sigma_{\gamma f}$ in the gamma energy range 5-12 MeV and the anisotropy at maximum energies $E_{\gamma max}$ of 6-15 MeV.

The experiments were performed in betatron chambers at the Leningrad Technological Institute. The target was a uranium layer 150 μg/cm^2 thick (90% ^{235}U, 1.4% ^{234}U, 8.6% ^{238}U). Mica was used for detecting the fission fragments and standard methods of processing and counting were employed.

For studying the photofission yield, the target and the mica detector were oriented along the axis of the gamma beam. The angular distribution of the fission fragments was recorded in a sector chamber with a radius of 34.4 mm at the centre of which a target with a diameter of 3 mm was positioned at an angle of 45° to the axis of the gamma beam.

The photofission yield (in relative units) is given in Fig. 1. The statistical error of the measurements did not exceed 3%, while the standard deviation of the points on the yield curve was determined mainly by the error assumed to be associated with the ionization chamber (~10%).

The calculations of $\sigma_{\gamma f}$ were performed using the method of Penfold and Leiss [1] with a 0.5 MeV interval and a 0.1 MeV shift at the interval limits with respect to the yield curve approximated by Chebyshov polynomials by the least-squares method. An irregular structure is observed in $\sigma_{\gamma f}$ at E_γ = 5.5, 6.3, 7, 8.1, 10.4, 11.4 MeV; it correlates with measurements [2,3] performed on monoenergetic photons and in part with data [4] on bremsstrahlung. The general shape of the cross-section in the energy range 5-8 MeV is similar to that found in Ref. [2]. Within the error limits, the previously determined thresholds 5.31 MeV [5] and 5.75 MeV [6] are in agreement with the values of 5.35 MeV and 5.65 MeV measured by the authors. The emissive fission threshold is 9.8 MeV (see Fig. 1). The difference between this value and the emissive fission threshold value given by Bowman [3] is greater than the possible uncertainty associated with the energy scale in the authors' experiment. In accordance with the "MDB" theory the lower emissive fission threshold can be explained in terms of the height difference between the A and B barriers of ^{234}U.

Fig. 2 shows the anisotropy of the b/a ratio found by representing the angular distributions of the functions $w = a + b \sin^2 \vartheta$ by the least-squares method for nine intervals of the angle ϑ, as a function of $E_{\gamma max}$. The b/a values are corrected for the number of even-even nuclei using anisotropy data from Ref. [7]. The data on anisotropy indicate that it varies non-monotonically when the sign changes in the region of 8, 10, 10.6 MeV. The negative anisotropy near 13.7 MeV probably corresponds to the ^{234}U emissive fission threshold. The positive anisotropy value for $E_{\gamma max} = 7$ MeV was obtained from three measurements.

The peak on the cross-section curve at $E_{\gamma} = 7$ MeV and, in part, the trough in the region 8-10 MeV may be due to the difference in the anisotropy sign. Investigations are continuing.

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Fig. 1 Energy dependence of the total yield of ^{235}U photofission, $Y(E_{\gamma max}) - 0$.
The broken line denotes the dependence of the photofission cross-section $\sigma_{\gamma f}$. The signs x and ▲ denote the results reported in Refs [3] and [2] respectively. The arrow denotes neutron separation energy.

Key: 1. E_{γ} (MeV)

2. Y (units illegible in original)

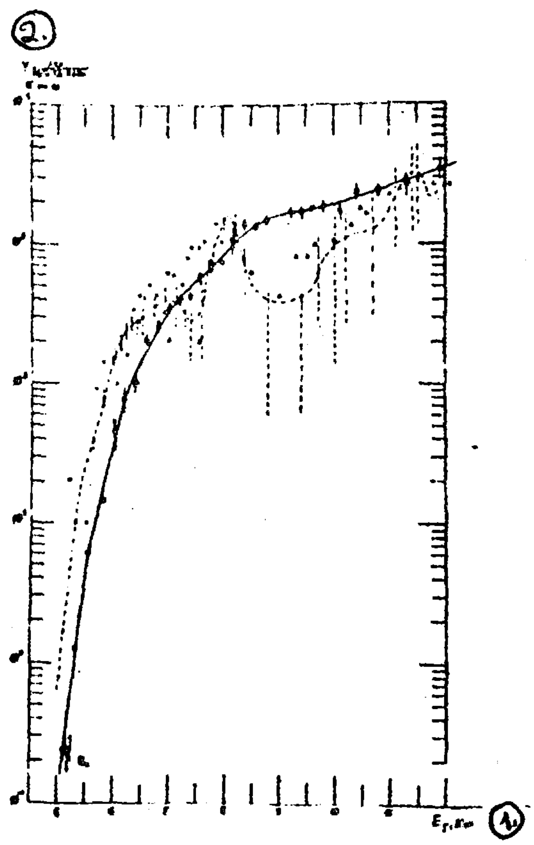

Рис. I. Энергетическая зависимость полного выхода фотоделения ^{235}U $Y(E_{\gamma max})$-0. Пунктиром проведена зависимость сечения фотоделения $\sigma_{\gamma f}$. Значками x и ▲ показаны соответственно результаты работ [3] и [2]
Стрелкой указана энергия отделения нейтрона.

Fig. 2 Angular distributions of ^{235}U fission fragments and values of b/a.

The numbers on the graphs denote maximum bremsstrahlung energy. The signs ▮ and ▲ denote the results reported in Refs [8] and [9] respectively.

Key: 1. ϑ, (degrees);

2. E_γ (MeV)

3. N(ϑ);

4. b/a

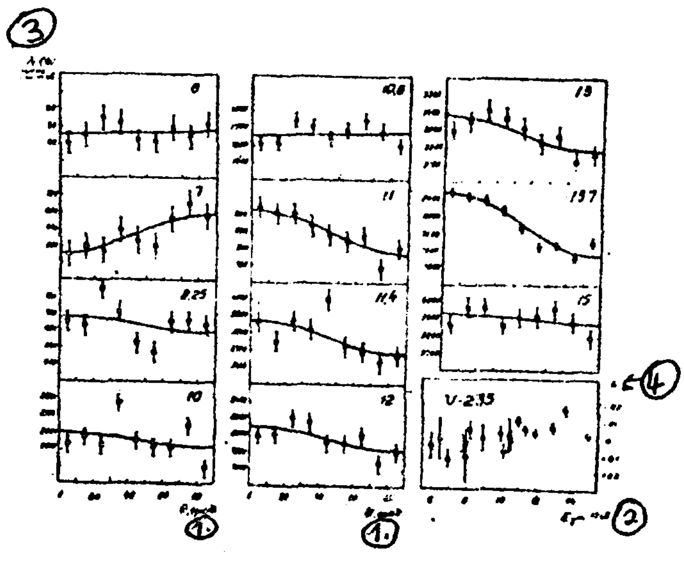

Рис. 2. Угловые распределения осколков деления ^{235}U и значения b/a. Цифры на графиках обозначают максимальную энергию тормозного излучения. Значками ▮ и ▲ обозначены данные работ [8] и [9].

Scientific Research Institute for Nuclear Reactors

$\bar{\nu}_p$ IN SPONTANEOUS ^{244}Cm, ^{246}Cm and ^{248}Cm FISSION

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Except for ^{244}Cm, the published data on cadmium isotopes [1-3] possess a low degree of accuracy (3-7%). It was therefore decided to measure $\bar{\nu}_p$ for ^{244}Cm, ^{246}Cm and ^{248}Cm under identical conditions and using the same experimental set-up to within ~1%. The results of such measurements by G.N. Smirenkin et al. [4] became known to the authors only after the completion of the work summarized here.

In the measurement of $\bar{\nu}_p$, fission fragments recorded by a gas-filled scintillation detector triggered a gating circuit for 180 μs, during which neutron pulses were recorded. The fission neutrons were recorded by 48 SNM-18 proportional counters placed in a paraffin moderator 500 mm in diameter and 500 mm long with a central through-channel 90 mm in diameter for the fission fragment detector. The efficiency of recording of spontaneous ^{252}Cf fission neutrons was 29%. The measurements of $\bar{\nu}_p$ for the isotopes of interest were performed relative to ^{252}Cf, the $\bar{\nu}_p$ value of which was taken to be 3.756 ± 0.010 [1].

The results of these measurements are compared with the results obtained by other authors in Table 1, from which it can be seen that they are in good agreement with the results presented in Ref. [4] and indicate a linear growth in $\bar{\nu}_p$ for even isotopes of curium with increasing mass number.

Values of $\bar{\nu}_p$ for curium isotopes

	Present paper	G.N. Smirenkin et al. [4]	1970-71 data	
^{244}Cm	2.680 ± 0.027	2.700 ± 0.014	2.691 ± 0.032	1
^{246}Cm	2.927 ± 0.027	2.934 ± 0.014	3.20 ± 0.22	2
^{248}Cm	3.173 ± 0.022	3.157 ± 0.015	3.11 ± 0.09	3

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EFIKhAR - A LANGUAGE FOR THE DESCRIPTION, MACHINE STORAGE AND CALCULATION OF EVALUATED INTEGRAL EXPERIMENTS IN FAST CRITICAL AND EXPONENTIAL ASSEMBLIES

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EFIKhAR was devised for the exchange of information on evaluated experimental data obtained in integral experiments. It can, however, also be used for the machine storage of experimental and computational information and in calculations performed for the purpose of fitting neutron cross-sections. By devising a special language it is possible to avoid ambiguity in the description of experimental and computational data.

EFIKhAR is an extension of the language of the FIKhAR system, which was developed at the Scientific Research Institute for Nuclear Reactors for the calculation of the physical characteristics of nuclear reactors. It employs many ALGOL-60 constructions.

Standard designations are introduced for all standard quantities measured in integral experiments, for their errors and for their calculated values. By employing a number of specially developed programs it is possible to use standard designations in an ordinary ALGOL program without a description in that program. This enables one to carry out any additional processing of both the experimental and the computational information.

The values of the standard quantities for an arbitrary set of critical assemblies can be put into and stored in a specially developed machine ARKhIV (archive).

An EFIKhAR description of experimental data for one critical assembly is given as an example.