NEUTRON CONSTANTS AND PARAMETERS

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INVESTIGATION OF THE ^{232}Th NEUTRON CROSS-SECTIONS IN RESONANCE ENERGY RANGE

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The alternative path in the development of atomic energy is the uranium-thorium cycle. In connection with this, the measurements of the ^{232}Th neutron capture and total cross-sections and its resonance self-shielding coefficients in resonance energy range are necessary because of their low accuracy. In this work, the results of the investigations of the thorium-232 neutron cross-sections are presented. The measurements have been carried out on the gamma-ray multisection liquid detector and neutron detector as a battery of boron counters on the 120 m flight path of the pulsed fast reactor IBR-30. As the filter samples were used the metallic disks of various thickness and diameter of 45 mm. Two plates from metallic thorium with thickness of 0.2 mm and with the square of 4.5×4.5 cm^2 were used as the radiator samples. The group neutron total and capture cross-sections within the accuracy of 2-7% in the energy range of (10 eV – 10 keV) were obtained from the transmissions and the sum spectra of γ-rays from the fourth multiplicity to the seventh one. The neutron capture group cross-sections of ^{238}U were used as the standard for obtaining of thorium ones. Analogous values were calculated on the GRUCON code with the ENDF/B-6, JENDL-3 evaluated data libraries. Within the limits of experimental errors an agreement between the experiment and calculation is observed, but in some groups the experimental values are larger than the calculated ones.

Introduction

The creation of the alternative direction in the atomic power engineering on the base of uranium-thorium cycle intends preliminary the production of the precise nuclear data for thorium-232, uranium-233 and protactinium isotopes [1,2]. Up until now, it was essential to study the neutron capture cross-section, a resonance self- shielding and their temperature dependence, e.g. Doppler effect in neutron cross-sections, important for the nuclear safety problems solving. Now there are the experimental data, which were obtained with accuracy of 1-6%, but they have a discrepancy of up to 50%. Recently, we carried out the preliminary measurements of the radiative capture in the energy range 21.5- 215eV [3] and also transmissions and Doppler coefficients in them for thorium-232 [4].

After the modernization of the multisectional (n,γ)-detector of the Romashka type [5] and the construction of the installations on the base of germanium detector, we started the thorium - 232 neutron capture and total cross-section measurements within 20 eV - 10 keV resonance energy region. After this, we intend to carry out similar investigations with the uranium - 233 and protactinium isotopes.

Experimental technique

The measurements of the neutron capture and total cross-sections were being carried out on the 121 m (124 m) neutron flight paths of the IBR-30 (W = 10 kW, f = 100 Hz, $\tau = 4\ \mu$sec) with the 16-section liquid detector of volume 80 l and the neutron boron detector. The general scheme is given in Fig. 1.

The hole of the lead collimator in front of the (n,γ)-detector was 70 mm diameter. The B_4C and Cd filters were placed in the beam for removing the background of recycled neutrons. The filter samples were made from the thorium oxide and the metallic thorium discs of various thickness. Two plates from metallic thorium with total thickness of 0.2 mm and with the square of $S = 4.5\times4.5\ cm^2$ were used as the radiator samples in the liquid detector. The U_3O_8 powder with uranium-238 (99.999%) and by weight of 3.86 g, contained in the aluminum tank with the 46 mm inside diameter, was served as the standard radiator as well. The 16-section liquid detector is described in [5]. From the moment the measurements started, the vary detector had a new lead shielding with thickness of 10 cm. The shape of the lead shielding was changed. The neutron detector in the form of a battery of three boron counters SNM-13 placed into a polyethylene disc 100 mm in diameter and 15 mm in thickness, was within 124 m from the IBR-30 fuel core moderator. The liquid detector operated in the multiplicity coincidence spectrometry conditions. Figs. 2 and 3 show typical apparatus time-of-flight spectra. The background components from natural radioactivity are low, and the effect - background ratio for the liquid detector in third multiplicity spectrum is 100% at best. The background for the boron neutron detector is 5-10%. The SNM-12 counter was used as monitor.

The processing technique and the results of measurements

Some runs of measurements were performed with the help of the liquid (n,γ)-detector having used in turn the ^{232}Th radiator sample and ^{238}U one. The measurements with the neutron boron detector were carried out, when the thorium and uranium radiator samples were not in the liquid detector. After the background components had been subtracted and the time-of-flight spectra had been brought mutual monitor coefficient, one determined a number of counts in the energy groups of the BNAB constants system [6] over the energy region of 20 eV – 10 keV. The number of counts within the energy groups are connected with a neutron flux and the neutron capture cross-section for ^{238}U and ^{232}Th of the following relations:

$$N_c^U / M^U = S^U n^U \langle\sigma_c\rangle^U \varepsilon^U(E)\varphi(E),\quad N_c^{Th} / M^{Th} = S^{Th} n^{Th} \langle\sigma_c\rangle^{Th} \varepsilon^{Th}(E)\varphi(E), \qquad (1)$$

where: M^U and M^{Th} are the monitor coefficients for the U and Th, S^U and S^{Th} are the areas , n^U and n^{Th} are the thickness of radiator samples , $\varepsilon^U(E)$ and $\varepsilon^{Th}(E)$ are the gamma-rays efficiencies of registration, $\varphi(E)$ is a neutron flux.

Supposing that the gamma-rays efficiency of registration for the uranium and thorium samples is the same, one may get from relations (1) the expression to determine a capture cross -section according to a know ^{238}U capture cross section:

$$\langle\sigma_c\rangle^{Th} = \langle\sigma_c\rangle^U M^U S^U n^U N_c^{Th} / M^{Th} S^{Th} n^{Th} N_c^U \qquad (2)$$

The mentioned liquid detector made it possible to define the time-of-flight spectra for 16 multiplicity of coincidences. However, as there had been observed the influence of scattered neutrons in the first three multiplicity, the summation of the spectra from the fourth multiplicity to the seventh one was performed. At this stage, a neutron capture was not observed with the eighth multiplicity spectrum.

After that the grouping of total spectra was being done, and the ^{232}Th - group capture cross-section, according to formula (2), was being determined. The group capture cross-sections of the ^{238}U were obtained by the calculation according to the GRUKON program [7] on the basis of the evaluated data of various libraries.

The experimental and calculated values of the group neutron capture cross-sections for thorium-232 and uranium-238 are shown in Table 1. The experimental errors of the capture cross sections are about 7-10%. It is seen from Table 1 that within the limits of experimental errors there is observed an agreement between the experiment and calculation, but in the group 17 an experimental value is larger than the calculated one.

The total transmissions were measured on three ^{232}Th filter samples with thickness of 0.01303 at/b, 0.02655 at/b and 0.0517 at/b. The group transmissions and observed cross-sections were determined by following formulas:

$$T_t(n, E, \theta) = {}_{\Delta E}\int \varphi(E)\varepsilon(E)e^{-\sigma(E,\theta)n}dE / {}_{\Delta E}\int \varphi(E)\varepsilon(E)dE = (N_s - F_s)M/(N_{o/b} - F_{o/b}),\ \sigma_t^{ob} = (-\ln T_t)/n, \qquad (3)$$

where: $\varphi(E)$ is the neutron flux, $\varepsilon(E)$ is the detector efficiency, σ_t is the total cross-section, n is the thickness of the filter sample, E is the neutron energy , θ is the temperature of the filter sample, N_s and $N_{o/b}$ are the detector counts with sample and without it, F_s and $F_{o/b}$ are the detector backgrounds, M is the monitor coefficient, σ_t^{ob} is the observed total cross-section.

The group total cross-sections were obtained by extrapolating the observed experimental ones to zero thickness of the filter sample, i. e. by multiplication of the observed cross-sections by the calculated coefficients of the self-shielding:

$$\langle\sigma_t\rangle^{exp} = K_{sh}\sigma_t^{ob}(n),\ K_{sh} = \langle\sigma_t\rangle^{cal}/\sigma_t^{cal}(n), \qquad (4)$$

where: $\langle\sigma_t\rangle^{exp}$ and $\langle\sigma_t\rangle^{cal}$ are the experimental and calculated group total cross-sections, $\sigma_t^{ob}(n)$ and $\sigma_t^{cal}(n)$ are the experimental and calculated the group observed total cross-sections for the filter sample n at/b thick.

The experimental and calculated group total cross-section for thorium-232 are shown in Table 2.

The group transmissions and cross-sections are averaged over Fermi spectrum. The experimental uncertainties of transmissions are 0.2–0.5%, the errors of the total cross-sections are 2-10%. The total transmissions are usually measured at $n\sigma_t$ = 0.2–0.4. This leads to underestimating the average group cross-sections by 20-40% in the region of unresolved resonance, if the correction for the resonance self-shielding of the averaged cross-sections is not introduced.

Conclusion

The measurements of the neutron capture cross-sections and transmissions were carried out and, using them the group total cross-sections of the ^{232}Th in the 10 eV – 10 keV energy region were determined. The analogous integral characteristics for the ^{232}Th were obtained on the basis of the evaluated data of ENDF/B-6 and JENDL-3.

In future, we intend to continue work in this direction to determine self-indication functions in neutron capture and on their base to define the resonance self-shielding factors.

Table 1.

The experimental and calculated neutron capture cross-sections of the ^{232}Th and ^{238}U

N_{gr}	E_{gr}, keV	$<\sigma_c>^{Th}$. b	$<\sigma_c>^{Th}$ [8]	$<\sigma_c>^{Th}$ [9]	$<\sigma_c>^{U}$ [8]
12	10.0 - 4.65	0.86 ± 0.10	0.867	0.899	0.814
13	4.65 - 2.15	2.04 ± 0.20	1.421	1.19	1.24
14	2.15 - 1.0	2.34 ± 0.20	2.104	1.79	1.70
15	1.0 - 0.465	3.96 ± 0.40	3.380	2.75	3.32
16	465 - 215 eV	5.79 ± 0.60	8.62	7.60	4.55
17	215 - 100	20.67 ± 3.00	14.53	14.68	20.3
18	100 - 46.5	19.24 ± 2.00	21.91	21.80	16.6
19	46.5 - 21.5	57.00 ± 5.00	54.0	54.4	54.2
20	21.5 - 10	-	0.662	0.641	0.841

Table 2.

The experimental and calculated total transmissions and cross-sections of the ^{232}Th

N_{gr}	E_{gr} (keV)	T_t (5 mm)	T_t (10 mm)	T_t (20 mm)	$<\sigma_t>$ (b)	$<\sigma_t>$ [8]	$<\sigma_t>$ [9]
12	10.0 - 4.65	0.804	0.648	0.443	17.7 ± 0.8	16.4	17.3
13	4.65 - 2.15	0.792	0.651	0.444	19.6 ± 0.9	19.0	19.9
14	2.15 - 1.0	0.794	0.648	0.465	21.9 ± 0.9	20.7	21.4
15	1.0 - 0.465	0.788	0.653	0.465	24.9 ± 1.1	23.9	22.1
16	465 - 215eV	0.790	0.661	0.481	33.5 ± 1.3	32.9	32.2
17	215 - 100	0.791	0.659	0.485	45.3 ± 1.5	41.8	43.6
18	100 - 46.5	0.795	0.670	0.487	71.8 ± 3.0	65.5	65.3
19	46.5 - 21.5	0.775	0.640	0.489	74.6 ± 4.0	71.9	73.2
20	21.5 - 10	0.843	0.729	0.532	12.4 ± 0.6	11.1	11.5

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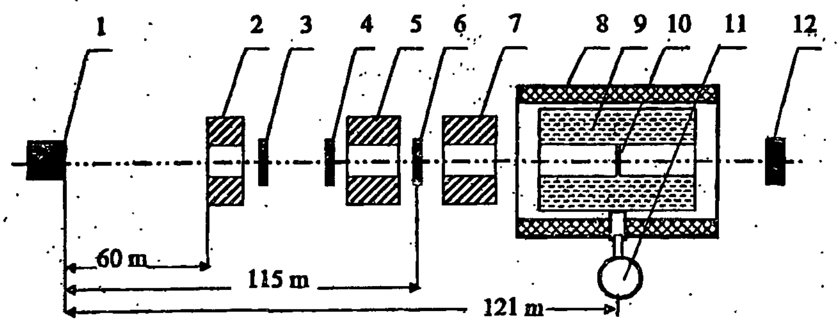

Fig. 1. The general scheme of the experiment:
1- IBR-30 fuel core moderator, 2, 5, 7 - collimators, 3 - Cd filter, 4 - monitor, 6 - Th sample - filter, 8 - lead shielding of the (n,γ)-detector, 9 - liquid detector, 10 - Th sample - radiator, 11 - HpGe-detector, 12 - neutron detector

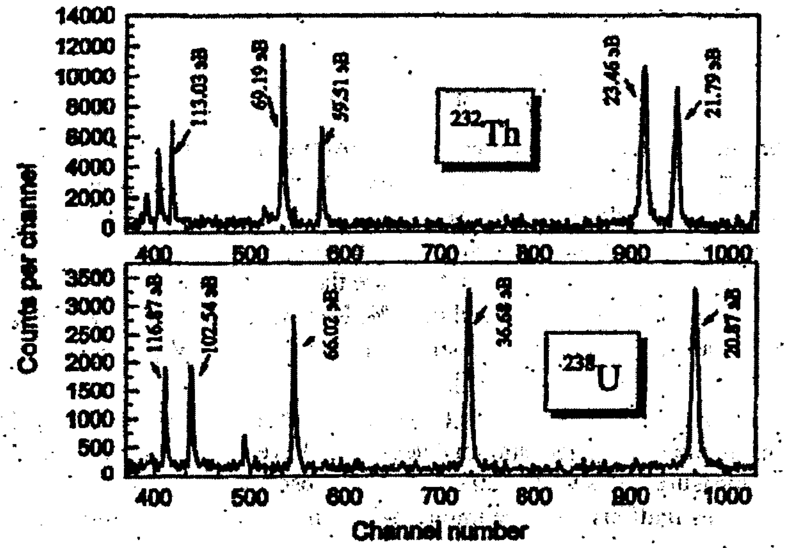

Fig. 2. The time-of-flight spectra of γ-ray coincidence summed from the 4^{th} to 7^{th} multiplicity for ^{232}Th and ^{238}U. (The time channel width – 2 μsec).

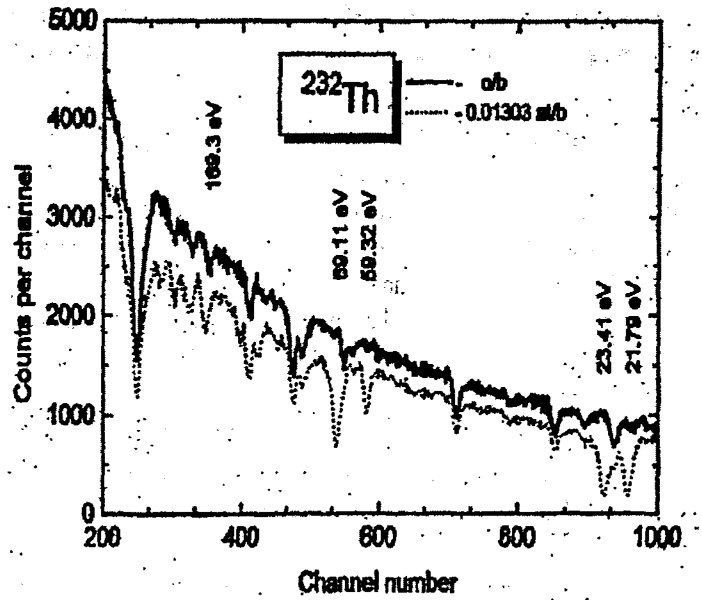

Fig. 3. The time-of-flight spectra of neutron detector for the open beam and with ^{232}Th sample -filter. (The time channel width – 2 μsec).