THE ESTIMATION OF SCISSION NEUTRON PARAMETERS FROM N-F AND N-N ANGULAR CORRELATIONS IN ^{235}U(n_{th},f) REACTION

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Abstract

With the aim to investigate the process of neutron emission two experiments on studying of neutron-fragment and neutron-neutron angular correlations in ^{235}U(n_{th},f) reaction were carried out in PNPI recently [1,2].

The neutron spectra for different angles as well as the angular dependences of neutron-fragment and neutron-neutron coincidence rates from these experiments were compared with the results of calculations based on Monte-Carlo method. In process of calculation it was assumed that the major part of fission neutrons evaporates from fully accelerated fragments but a fraction of total number of fission neutrons can be emitted isotropically in the laboratory system.

From the comparison of experimental data connected to both n-f and n-n angular distributions simultaneously with the results of Monte-Carlo calculations it was concluded that about 7% of total number of neutrons in ^{235}U(n_{th},f) reaction are emitted isotropically and probably can be attributed to “scission neutrons” arising just at the rupture moment. The form of this component corresponds to Weisskopf distribution with temperature parameter $T \approx 1$ MeV.

It is reliably established that most of prompt neutrons are evaporated during the fission process by fully accelerated fragments. This conclusion is based on the fact that instead of isotropic neutron distribution in laboratory system of reference, a considerable increase of neutron yield is observed in the direction of the light fragment motion and in the opposite direction. In the former case a part of neutrons emitted from heavy fragment is small and the total spectrum is very close to the neutron spectrum produced by the light fragment. On the other hand at 180° the contribution of neutrons from the light fragment is negligible and the neutron spectrum is shaped by the heavy fragment.

The peculiarity of neutron spectra at these angles can be used to determine the neutron spectra in the centre-of-mass for the light and heavy fragment, respectively, and corresponding temperature parameters. It is known the form of neutron spectrum in the centre-of-mass of each fragment is very close to Maxwellian distribution. On the base of obtained temperature parameters and taking into account final velocities of accelerated fragments one can calculate the neutron yield in any direction of the lab-system.

The results of calculations for angular distributions in the reaction ^{235}U(n_{th},f) performed in the frame of neutron emission from fully accelerated fragments show the difference between experimental data and calculated curve [3]. Such discrepancy can be minimised if one supposes that a fraction of total number of fission neutrons can be emitted isotropically in laboratory system of reference. It is assumed that the neutrons of isotropic component can appear just after the rupture point (so-called “scission” neutrons). The contribution of isotropic component evaluated by Skarsvag is about 15%. But this value is still under question because in the literature we can find a lot of different results for similar estimations.

As state above, now we have our own experimental data on neutron-fragment angular distributions in slow-neutron-induced fission of ^{235}U [1]. To describe these distributions and evaluate the contribution of isotropic component it is necessary to have neutron spectra in fragment centre-of-mass. With this object in mind we also used experimental neutron spectra at zero and 180 degrees in laboratory system of frame. Although the shape of neutron spectra in fragment centre-of–mass is very close to Maxwellian distribution, it was decided to use direct numerical values of neutron spectra obtained with the help of Jackobian transformation.

The anisotropy of neutron emission due to the presence of angular momentum of fission fragments was also taken into account [4]. In process of calculation were used energy dependences of angular anisotropy for the light and heavy fission fragments with the most probable masses. The solid curves in the figure 1 demonstrate the results of Monte-Carlo calculations of neutron emission anisotropy for both fragments. These estimations were performed with averaged initial angular momentum 7 (for light) and 8 (for heavy) fragments, respectively. The dashed curves show corresponding neutron spectra, whose shapes determine the value of averaged anisotropy for each fragment. They were estimated as 6.3% for light and as 9.5% for heavy fragment, respectively.

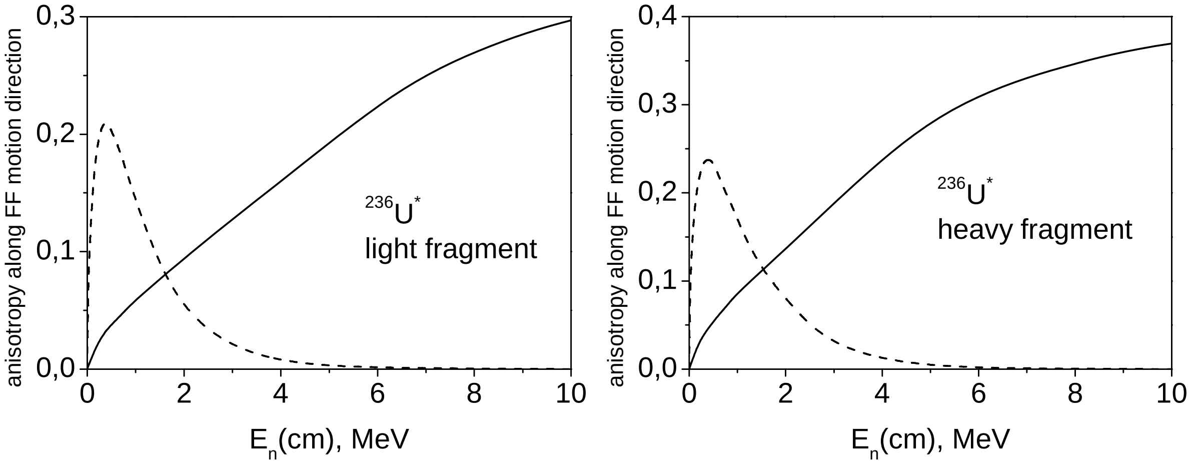


Fig.1. Anisotropy of neutron emission for light and heavy fragments (solid lines). The dashed curves show corresponding neutron spectra in fragment centre-of-mass.

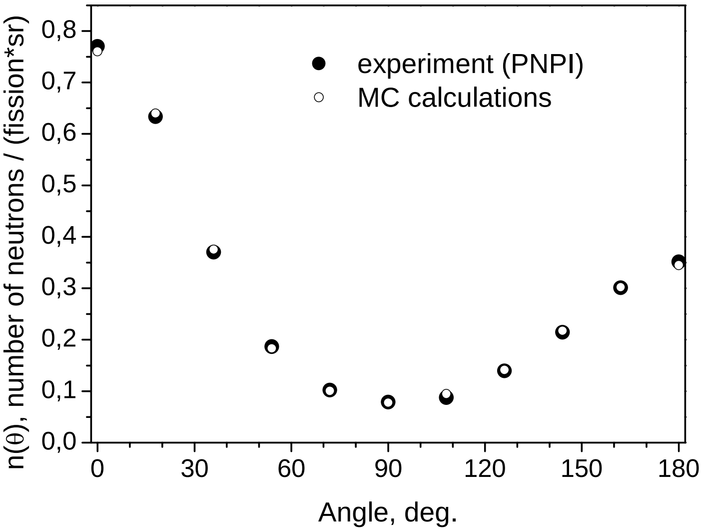
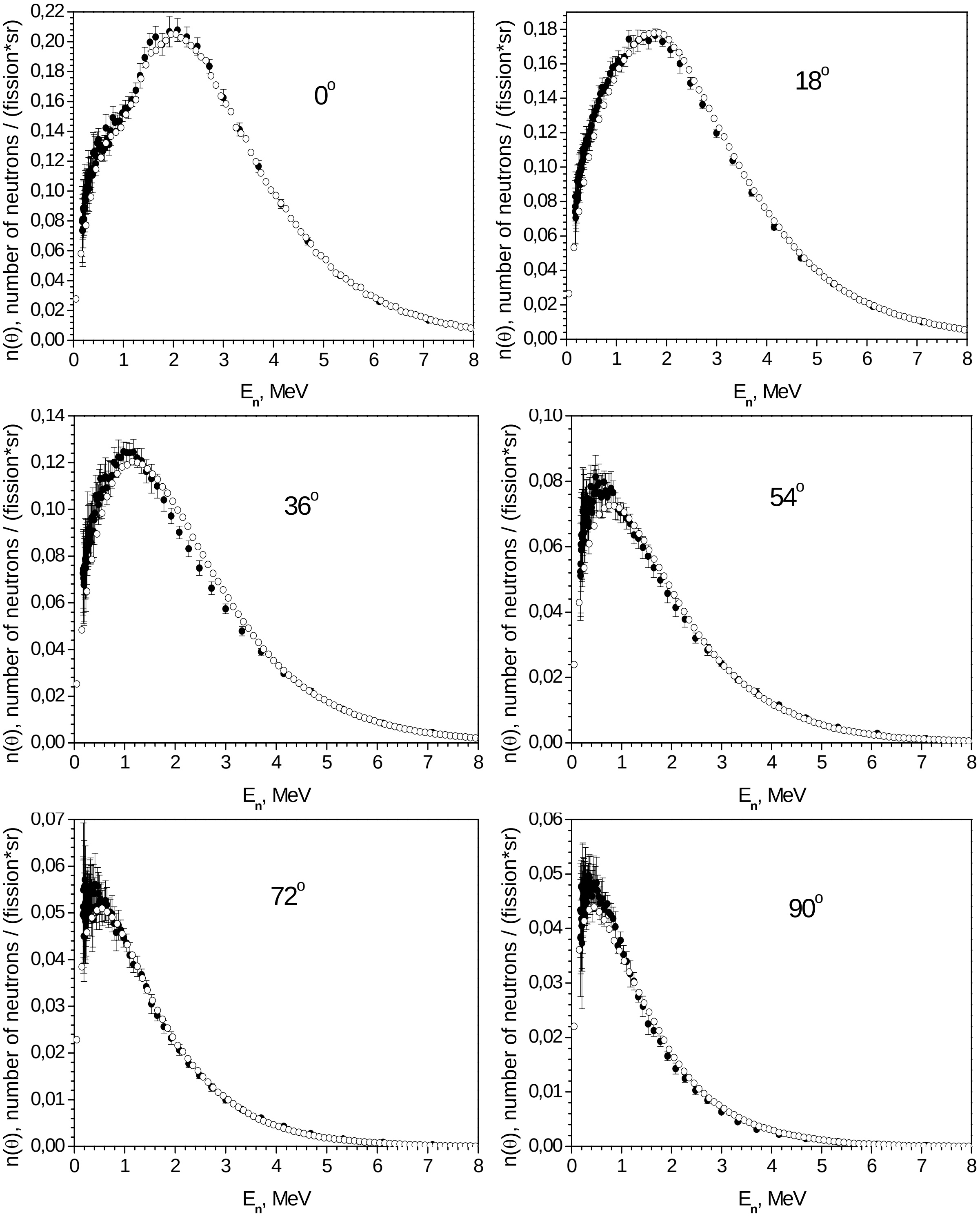


Fig.2. Experimental data and the result of MC calculations for energy integrated angular dependence of neutron yields.

Finally together with neutrons evaporated from fully accelerated fragments we also had to add 7% of neutrons concerned with isotropic component to describe the angular distribution of neutron yields. The energy distribution for this component was assumed Weisskopf form with temperature 1 MeV.

The figure 2 shows experimental data and calculated results integrated over all values of neutron energy.

The next eleven illustrations in the figure 3 demonstrate more detailed picture, namely: experimental neutron spectra at different angles and corresponding results of Monte-Carlo calculations. As we can see the agreement is rather good.



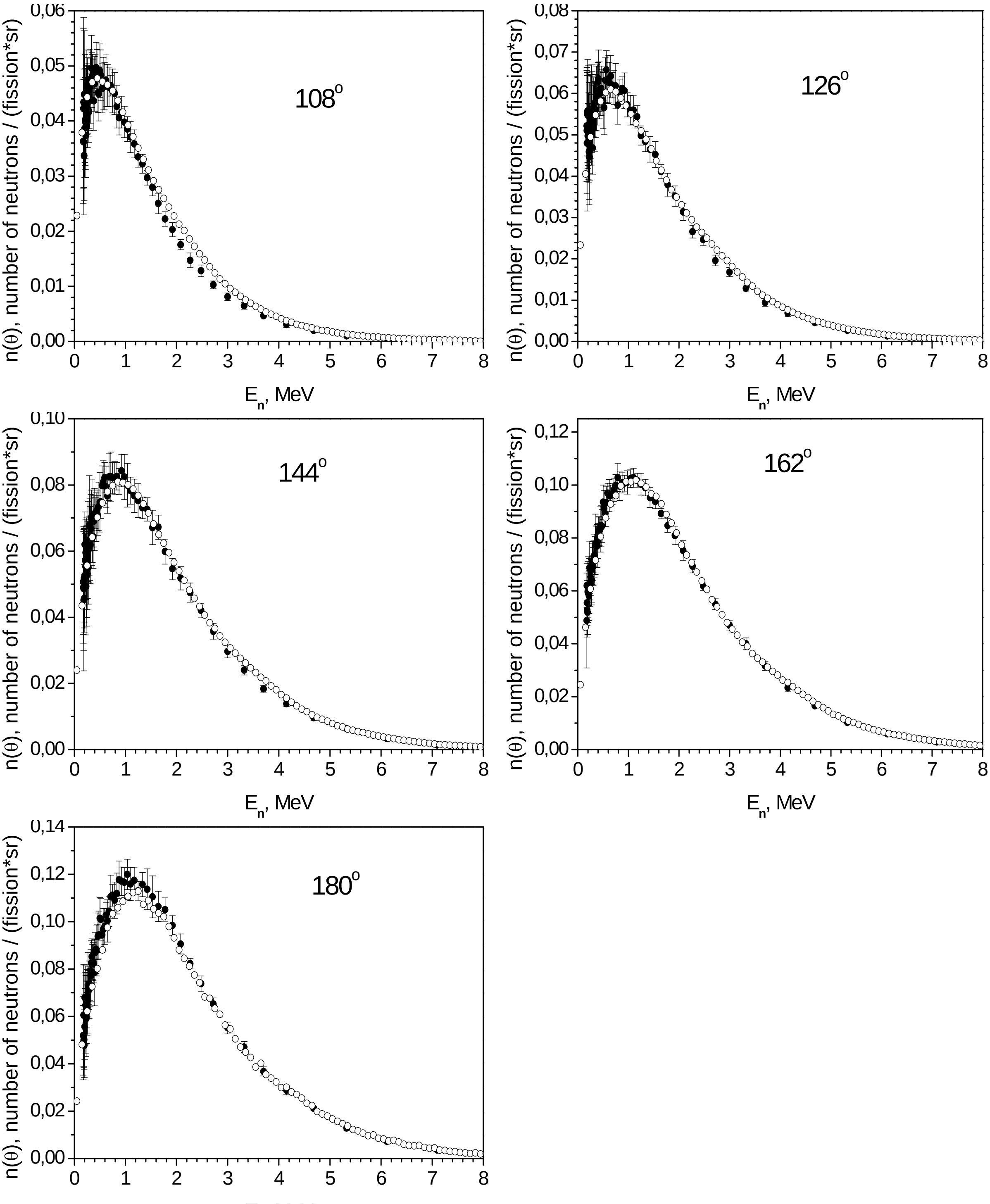


Fig.3. The comparison of experimental neutron spectra at different angles (●) observed in the reaction ^{235}U(n$_{th}$,f) and corresponding results of Monte-Carlo calculations (○).

With the aim to investigate the process of neutron emission the coincidences between prompt neutrons from fission can be also used. With this design the measurements of neutron-neutron correlations in slow neutron induced fission of ^{235}U were realised recently in PNPI [2].

In our experiment the angular dependences of n-n coincidences integrated over all neutron energy values were measured for six different energy thresholds. This allowed us to get some information not only about the contribution of additional component but also concerning its energy distribution.

Since the thresholds of the detecting device were set by the scale graduated against γ-rays, the true values of the neutron energy thresholds were obtained in process of corresponding time-of-flight spectrum fitting. Every time-of-flight spectrum consists of γ-γ, n-n and γ-n components. The first two components are in the middle of the measured spectrum (see Fig.3 in [5]). Especially the scopes of γ-n component determine the neutron energy threshold.

Then neutron-neutron angular distribution was calculated for each neutron energy threshold. These calculations were based on the same assumptions as for description of neutron-fragment angular correlations. At the first stage of this calculation it was simulated neutron emission from both fragments with the addition of the necessary contribution of scission neutrons, namely 7%.

The averaged total multiplicity of emitted neutrons was taken as 2.42. The actual number of neutrons evaporated by each fragment was chosen randomly by two-dimensional Gaussian distribution with experimentally defined covariance and known ratio of averaged fragment multiplicities. We have got this ratio and neutron spectra in fragment centre-of-mass due to neutron-fragment experiment.

It was taken into account the presence of neutron emission anisotropy concerned with the angular momentum of each fragment.

In process of calculation were used final velocities of the light and heavy fission fragments with the most probable masses.

The Weisskopf form of energy distribution with temperature parameter 1 MeV for scission neutron spectrum was assumed.

Thus all input data for calculations were obtained from neutron-fragment angular correlations and we had no free parameters (including parameters of isotropic component) to describe n-n angular distributions.

The figure 4b demonstrates the Monte-Carlo predictions of n-n angular distributions in slow neutron induced fission of ^{235}U for our six neutron energy thresholds. All angular dependences were normalized to one at 90^{o}. As we can see the ratio between maximal and minimal values of n-n angular correlation depends very significantly on neutron energy threshold. For maximal value of energy threshold, namely 2030 MeV, this proportion is twice as much than for lowest one.

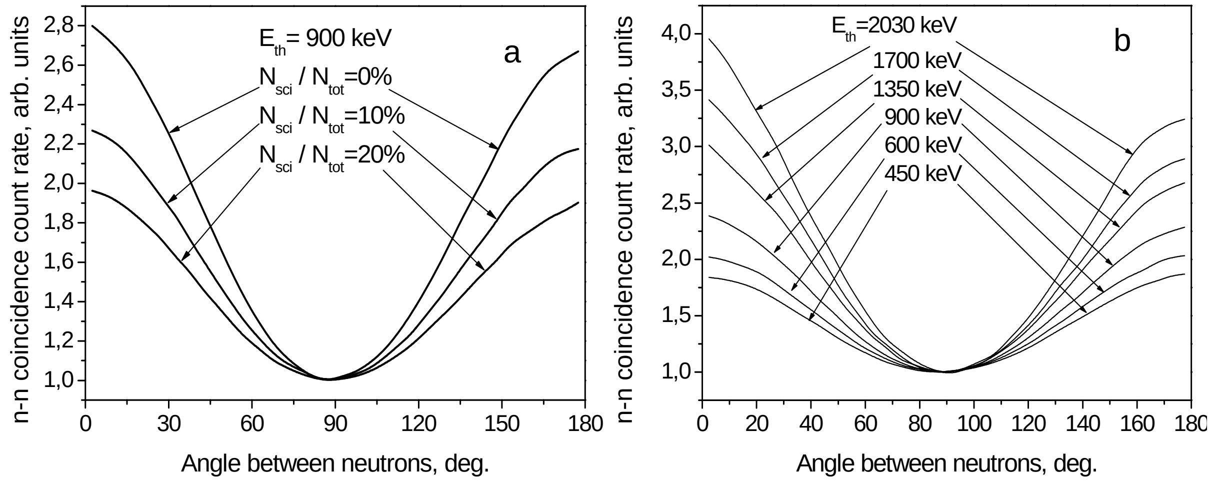


Fig.4. The influence of scission neutron contribution (a) and neutron energy threshold (b) on describing of n-n angular distributions.

We can compare calculated results with experimental data of neutron-neutron angular distributions. The next 6 pictures in the figure 5 represent such distributions for different neutron energy thresholds. As we can see our calculations are in a good agreement with experimental results.

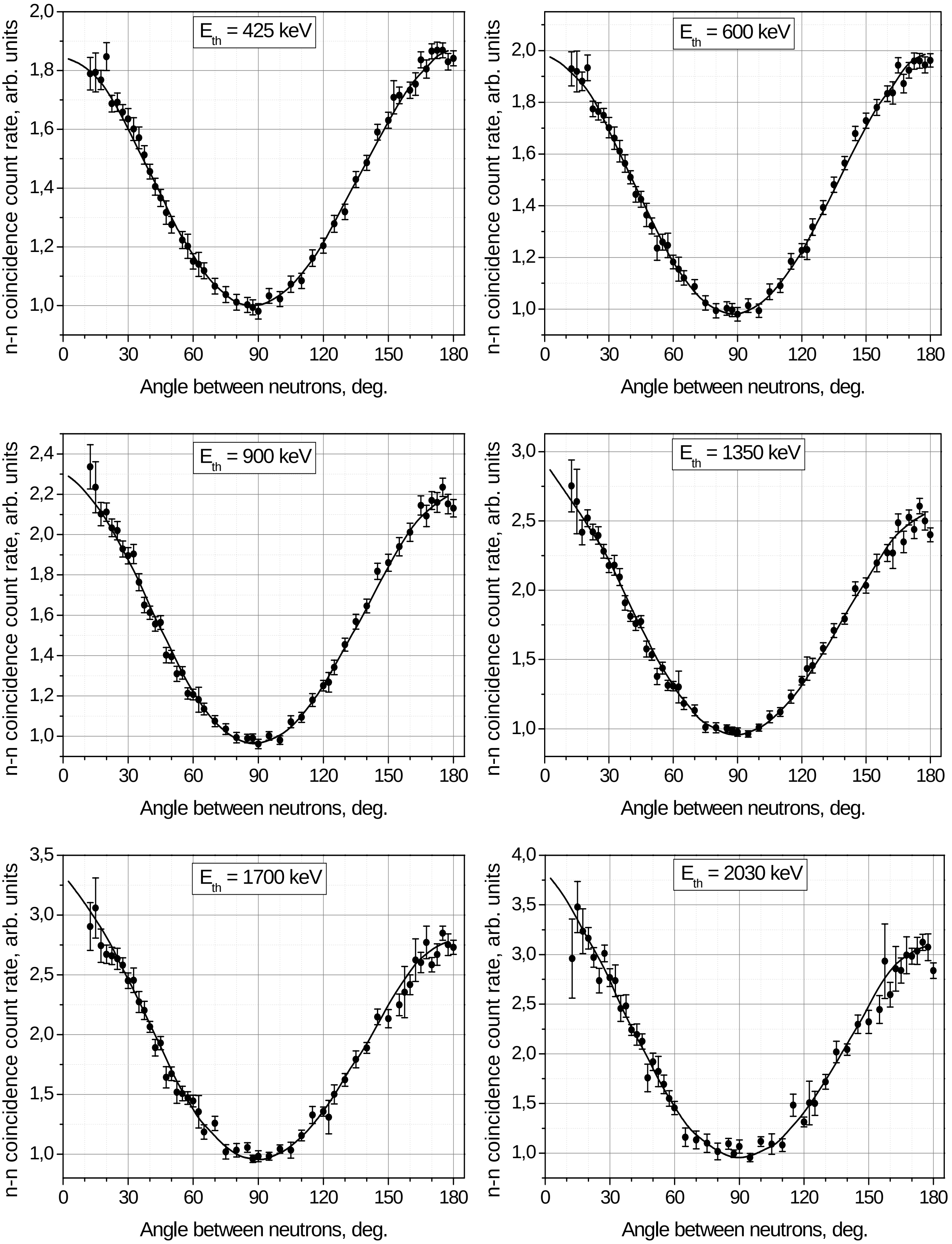


Fig.5. The comparison of experimental data and results of MC calculations for n-n angular correlations in the reaction ${}^{235}U(n_{th},f)$.

The figure 6 demonstrates the sensitivity of calculated values for n-n coincidence count rate to scission neutron contribution. It may be seen that all experimental data are practically bounded by two lines: with 5% and 9% contributions of isotropic in laboratory system component. This allowed us to evaluate the contribution of scission neutrons as (7±2)% for total number of emitted neutrons.

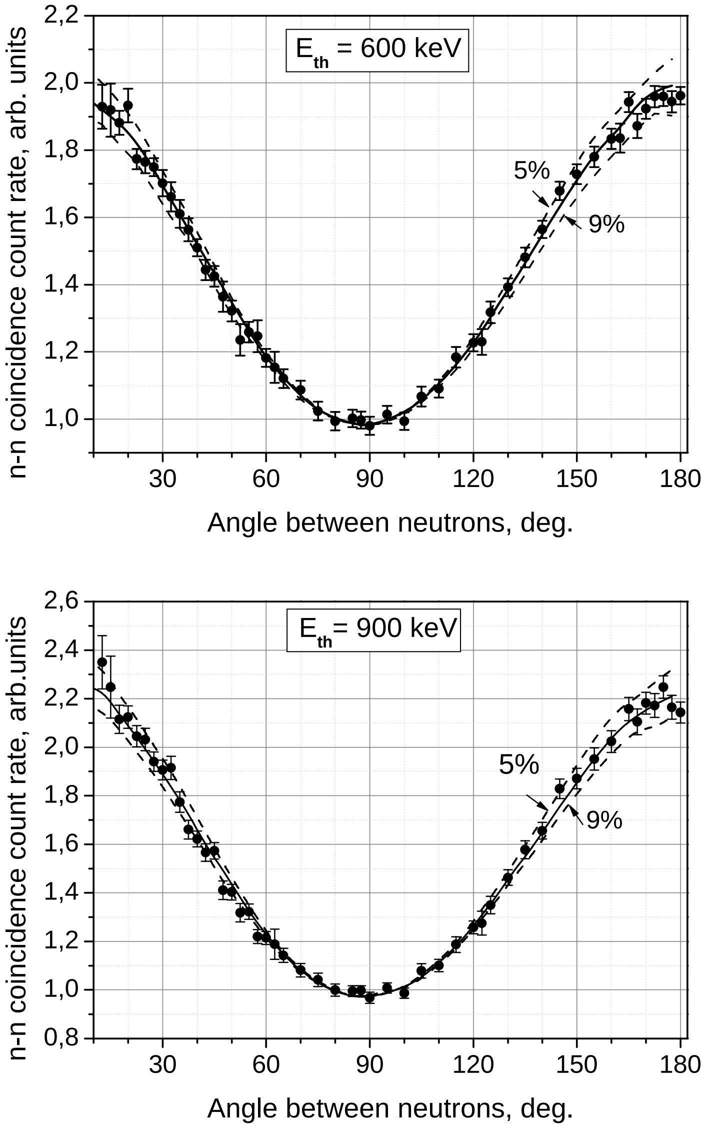


Fig.6. The sensitivity of calculated values for n-n coincidence count rate to scission neutron contribution. The solid curve corresponds to 7% of isotropic component, the dashed lines – 5% and 9%.

As a part of the previous report in proceedings of ISINN-15 [5] was the evaluation of scission neutron component using experimental data of Franklin [6]. These data also correspond to n-n angular distribution in slow neutron induced fission of ^{235}U but they were obtained only for three neutron energy thresholds. These data give us another result, namely 15%. Now we have an opportunity to compare both experimental data (Franklin and PNPI) connected practically with the same energy thresholds.

But before this it is necessary to recall how n-n angular distributions depend on the contribution of isotropic component and on neutron energy threshold. The two figures 4a and 4b demonstrate mentioned relations. As we can see the more the part of scission neutrons and lower energy threshold are supposed the planer calculated curve is.

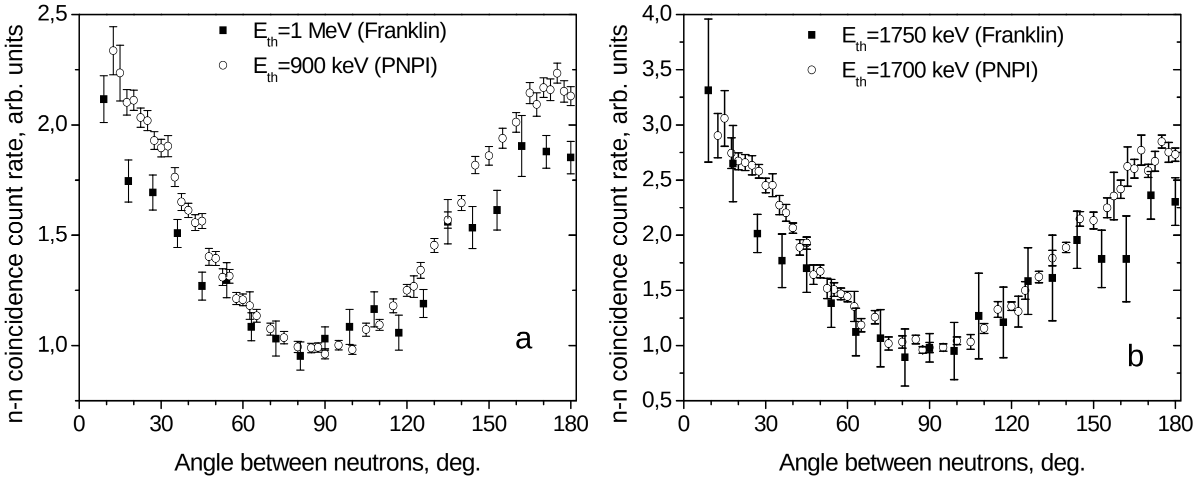


Fig.7. The comparison of our experimental data on n-n angular correlations with experimental data obtained by Franklin.

Let's go back to experimental data comparison. The figures 7a and 7b show n-n angular distributions for neutron energy thresholds near 1 MeV (a) and about 1.75 MeV (b). All data were normalised at 90 degrees. As we can see positions of our data are systematically above although they must be slightly below than Franklin's data if all neutron energy thresholds were right estimated. We are sure that our determination of energy threshold is correct but we do not know how this value was obtained by Franklin. Perhaps the discrepancy between energy threshold estimations is the reason of different values for isotropic component.

Conclusions:

Both experimental data (corresponded to n-f and n-n angular distributions) in slow neutron induced fission of ^{235}U can be well reproduced by Monte-Carlo calculations assuming neutron evaporation from fully accelerated fragments with the addition of (7±2)% isotropic component. The form of energy distribution of isotropic component is N~E·exp(-E/T) with T=1 MeV. During the calculation anisotropy of neutron emission due to the presence of fragment angular momentum was taken into account.

References:

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