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REMARKS ON THE EXISTENCE OF RETARDED NEUTRONS IN FISSION

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REMARKS ON THE EXISTENCE OF RETARDED NEUTRONS IN FISSION

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ABSTRACT

New measurements on "retarded" fission neutrons are critically discussed.

РЕЗЮМЕ

Критически исследовались экспериментальные обоснования существования задержанных нейтронов при делении ядер.

KIVONAT

Megmutatjuk, hogy a "retardált" hasadási neutronok létezése a jelenlegi kisérleti eredmények alapján nem bizonyitható.

INTRODUCTION

Over a long period of time, experimentalists at various laboratories, using different techniques, have shown remarkable convergence in measuring the energy spectrum of fission neutrons of different nuclei. Individual spectrum-shape measurements are in rather good agreement when suitably normalised and fitted either to a Maxwellian or to the Watt form, thus the neutron distribution is smooth function of the neutron energy [1]. Recently, however, Nefedov [2] and Zamyatnin et al. [3] have claimed the existence of a number of peaks on the fission neutron spectra. According to their interpretation the peaks are formed by "retarded" neutrons emitted by fragments of mass close to $A = 132$ during a time of the order 10^{-8} - 10^{-9} sec.

In this paper we attempt to revise critically the experimental proofs of the existence of retarded neutrons and to show another possible reasonable explanation for these experimental results.

NEFEDOV'S EXPERIMENTS [2]

A/ Multidimensional measurements were made of the spectra of ^{235}U fission neutrons as a function of the kinetic energy of the fission fragments, using the time-of-flight /TOF/ technique. Peaks were observed at energy levels 0.75, 1.2, 1.6 and 2.6 MeV, mainly on the neutron spectra of fragments with E_k = 80-83 MeV kinetic energy, indicating that these neutrons are emitted by fragments whose mass is close to $A = 132$.

The neutron energy resolution was poor, being 10% at 1 MeV and 16% at 2.5 MeV. The efficiency of the plastic scintillator was calculated theoretically. It seems unlikely that real peaks could have been observed in the spectrum under these experimental circumstances. Nefedov deduced the appropriate mass numbers from the measured kinetic energy values using the data of Milton and Fraser [4]. It is questionable, however, whether one can make such a comparison without any absolute calibration of the detector. Furthermore, fragments of E_k = 80-83 MeV kinetic energy correspond to mass numbers 110-111, and those with $E_k = 78-80$ MeV to mass numbers 112 and 130 [4], so the hypothesis that the emission of retarded neutrons is governed by the large initial angular momenta of fragments with mass number near 132 seems to be doubtful.

B/ In the next experiment Nefedov measured the total neutron spectrum and angular distribution of ^{252}Cf fission neutrons by TOF technique. The measurements were made above 0.65 MeV only, therefore it is rather difficult to conclude from this experiment alone that there is a peak at 0.7-0.8 MeV; moreover the most probable energy of neutrons from ^{252}Cf is, in fact, 0.75-0.8 MeV [5]. A dip can be seen only in the total spectrum at 1 MeV. Verification of this dip in the spectrum measured at 90° is uncertain considering the rather poor statistical accuracy.

C/ In another experiment the neutron spectra of ^{252}Cf were measured by TOF method at 0° and 180° relative to the direction of fragment flight. Nefedov observed peaks only in the spectrum measured at 0°. Measuring the angular distribution of neutrons from fission several authors [6] observed a dip at angles near 0°. This dip can be interpreted theoretically assuming an evaporation type of spectrum for neutrons in the center-of-mass system:

$$\varphi(\varepsilon) \sim \varepsilon . \exp\left(-\frac{\varepsilon}{T}\right)$$

Transforming the distribution to the laboratory system a minimum appears at the energy corresponding to the fragment velocity.

We made some calculations to investigate the effect caused by this irregularity. Isotropic evaporation was assumed from individual fragments in the c.m. system. The nuclear temperature parameters of the evaporation spectra were calculated from the measured average neutron kinetic energy data of [6]. The distributions were transformed into the laboratory system using the fragment velocity data of [7]. In this way we got the angular distribution of neutrons in the laboratory system for every fragment individually. The results of calculation for several fragments are plotted in Fig. 1 for the thermal fission of ^{235}U. There is a minimum in the neutron distribution at different energies depending on the flight velocity of fragments with different mass number. The angular distribution of neutrons from the fragment with $A = 102$ can be seen in Fig. 2. The neutron distributions were summed up for the different fragments taking into account the $\nu(A)$ and $p(A)$ distributions. $\nu(A)$, the average number of neutrons from fragments, was taken from the measured data of [6], the $p(A)$ distribution from the measured yield data of [8].

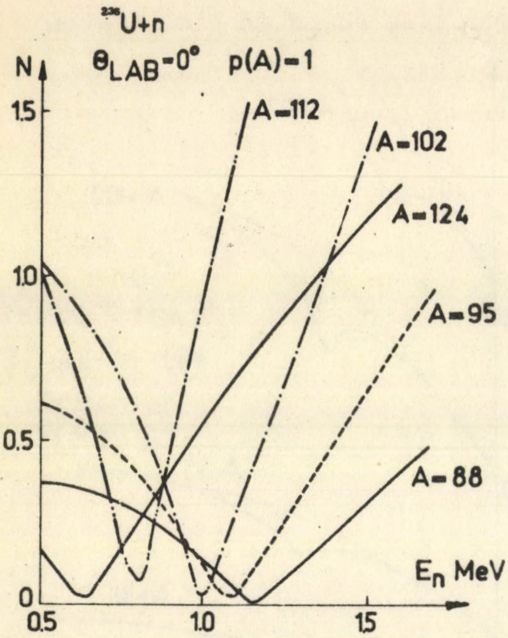

Fig. 1 Energy spectra neutrons at $\Theta_{LAB} = 0^0$ from different fragments $\varphi_{c.m}(\varepsilon) \sim \varepsilon . \exp\left(-\frac{\varepsilon}{T}\right)$

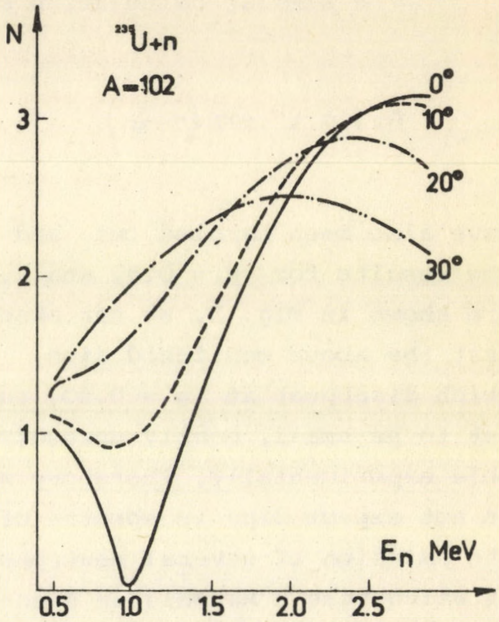

Fig. 2 Energy and angular distribution of neutrons evaporated from the fragment with mass number 102.

The results for ^{235}U thermal fission and for ^{252}Cf spontaneous fission are plotted in Figs. 3 and 4 respectively. /The ^{252}Cf date were taken from [7, 8, 9, 10]./ The neutron distributions have minima at small angles. Integrating the angular distribution over all angles these minima disappear.

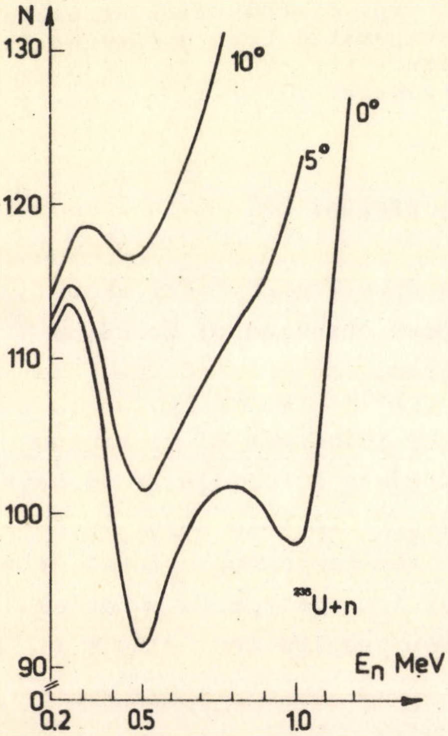

Fig. 3 The total energy and angular distribution of neutrons evaporated in the thermal fission of ^{235}U.

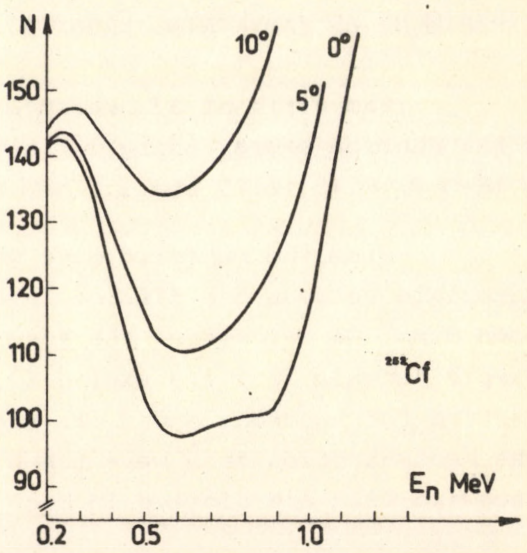

Fig. 4 The total energy and angular distribution of neutrons evaporated in the thermal fission of ^{252}Cf

A similar calculation assuming a spectrum shape in c.m. system:

$$\varphi(\varepsilon) \sim \varepsilon^{n}.\exp\left(-\frac{\varepsilon}{T}\right)$$

have also been carried out and the results for n = 0.52 and 0.50 are shown in Fig. 5. We can observe that the above mentioned dips, which disappear at n = 0.50, turn out to be small, mostly unresolvable experimentally. Therefore we do not expect dips in spectra of the emission of several neutrons, in which case a Maxwellian spectrum shape is the appropriate one [11]. But in cases of emission of one neutron only, a spectrum of the evaporation type with n = 1, can be used. It may be this which explains the existence of dip for some fragments with low excitation energy /A ∿ 132/.

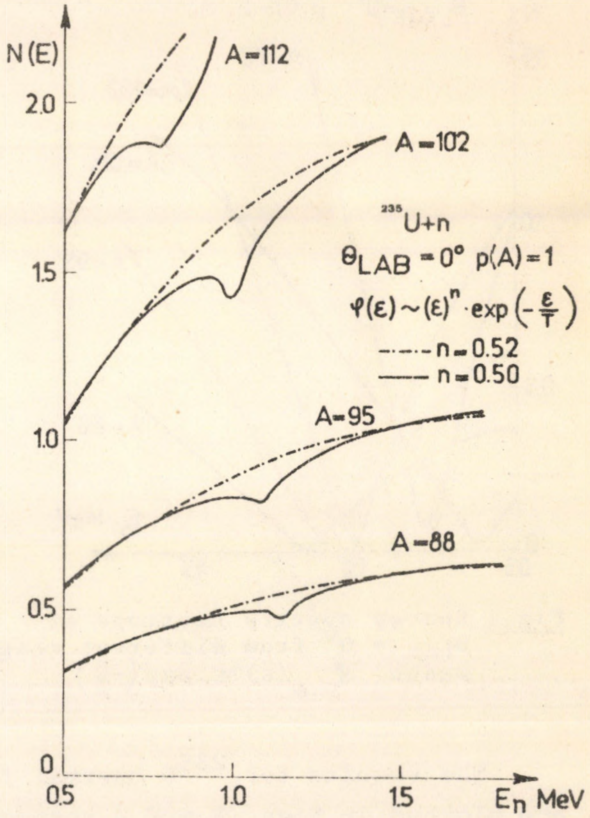

Fig. 5 Energy distribution of neutrons evaporated from different fragments for two types of c.m. spectra.

EXPERIMENT OF ZAMYATNIN, KROSKIN, MELNIKOV AND NEFEDOV [3]

Zamyatnin et al. measured the neutron spectrum of ^{252}Cf above 4 keV neutron energy using TOF method. Peaks were observed at 0.085, 0.18-0.2, 0.45, 0.75 and 1.2 MeV neutron energies.

From the reported data we estimated the thickness of aluminium materials between the fission layer and the Li-glass scintillator to have been 3 mm. We calculated the absorption of neutrons in this layer by the simple formula $N \sim 1 - \exp(-\mu.\ell)$, where μ is the macroscopic total cross-section for neutrons and ℓ is the thickness of the absorptive material. The cross-section data were taken from [12]. The results for $\Phi(E) = 1$ incoming flux are plotted in Fig. 6.

The scattered background was measured by placing an iron shadow cone of 20 cm length between the detectors. According to our calculations,

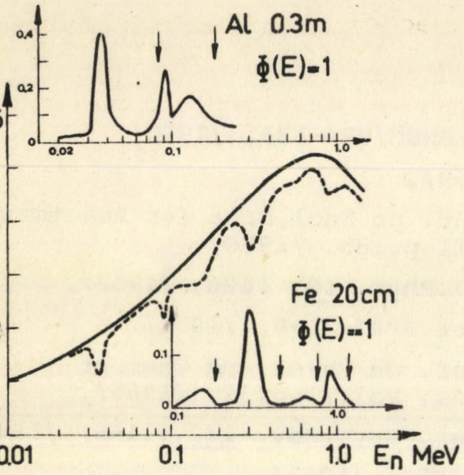

Fig. 6 The distortion of a Maxwellian-type energy distribution of neutrons caused by absorptive materials.

however, the iron cone could not have absorbed all the neutrons in the investigated energy range /see Fig. 6/. Therefore Zamyatnin and his coworkers must have measured a certain amount of direct neutrons in the scattered background. Assuming Maxwellian distribution for neutrons with T=1.5 MeV, we calculated the absorption caused by the aluminium materials and the contribution of direct neutrons as scattered background, which was duly substracted from the spectrum. The results of the calculations /see Fig.6/ strikingly well reproduced the measured data.

CONCLUSIONS

Our remarks indicate that the existence of real peaks /or some of them/ in fission neutron spectra is doubtful on the basis of the experiments surveyed and that consequently the conclusions drawn from these experiments concerning the origin and properties of "retarded" neutrons must also be questionable.

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