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ENERGY AND ANGULAR DISTRIBUTIONS OF NEUTRONS FROM ^{252}Cf SPONTANEOUS FISSION

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It is interesting to study the energy and angular distributions of fission neutrons because the neutrons seem to be emitted partly during the early stages of fission, before the fragments are fully accelerated by the Coulomb forces. A study of the characteristics of these neutrons may yield information on the state of the nuclei in the interval close to the moment when the fissionable nucleus separates into fragments. Since the first detailed papers [1, 2] were published in the early sixties, several theoretical and experimental studies (e.g. Refs [3, 4]) have been performed, but progress towards an understanding of the nature of the "separating" neutrons has been limited by the difficulties of setting up multiparameter experiments and the poor efficiency of the neutron spectrometers used.

In Ref. [4] we presented some results from a first series of measurements of energy and angular distributions of neutrons from ^{252}Cf spontaneous fission using a spectrometer with high neutron detection efficiency, i.e. a 4π neutron time-of-flight spectrometer [5]. Subsequently, a second series of measurements was performed using a more sophisticated technique. For this second series, we used a more intense ^{252}Cf layer (25 000 spontaneous fissions per second). The angular resolution was improved by a factor of 2-3 by combining the hexahedral counter modules, placed at the same angle with respect to the direction of motion of the fragments, in new panoramic counters. The neutron counters were calibrated against the average ^{252}Cf neutron spectrum at several positions of the axis of the fragment detector with respect to the neutron counters. In the spectrum measurements and calibration work, the scattered neutron background was not determined theoretically, as in the first series of measurements, but experimentally using four extra scintillation counters with scatter cones; the counters were set up at 60^{o}, 80^{o}, 100^{o} and 120^{o} to the direction of separation of the fragments.

During the second series of measurements, approximately 1.5×10^{6} fissions and 1.2×10^{6} neutrons were detected. During the counter calibration exercises, $\sim 2.5 \times 10^{6}$ fissions were recorded.

The time-of-flight distributions of the fragments and neutrons were mainly processed in the same manner as for the first series. The neutron distributions were sorted into eight ranges of heavy fragment mass M_H and total fragment kinetic energy $E_{t.k.}$; the number of fissions and the $\bar{M}_H$ and $\bar{E}_{t.k.}$ values for each range are shown in the table. For the counters at $\bar{\theta} \approx 90^o$, there were 20-30 full corrections and statistical errors of 5-8% in the neutron distributions. For the counters placed in the direction of motion of the fragments, the corrections and errors were several factors less. The neutron spectra were calculated separately for all the panoramic counters and then averaged over groups of four counters. As a result, neutron spectra were obtained at twelve $\bar{\theta}^o$ angles to the direction of motion of the light fragments in all eight M_H and $E_{t.k.}$ ranges.

The figure shows the experimental spectra for range 5 (R5) and the results predicted according to the theory of isotropic neutron evaporation from all the accelerated fragments. At $\bar{\theta} = 26^o$ and 154^o, the spectra coincide since at these angles the experimental spectra were used to calculate the parameters of the neutron spectra in the fragments' centre-of-mass system; at other $\bar{\theta}$ angles, the experimental spectra are more intense than the theoretical spectra. There are more "separating" neutrons at high $E_{t.k.}$ values, i.e. in R2, 4-5 and 7 compared to R1, 3 and 6, respectively. This result agrees with the data presented in Refs [3, 4]. It turned out, however, that at several $\bar{\theta}$ angles in the ranges with low $E_{t.k.}$ values (R3 and particularly R1 and 6), the experimental spectra were less intense than the theoretical spectra. This result may be due to the anisotropic angular distribution of the neutrons in the fragment system. We have begun to prepare calculations based on more complex fission neutron emission models.

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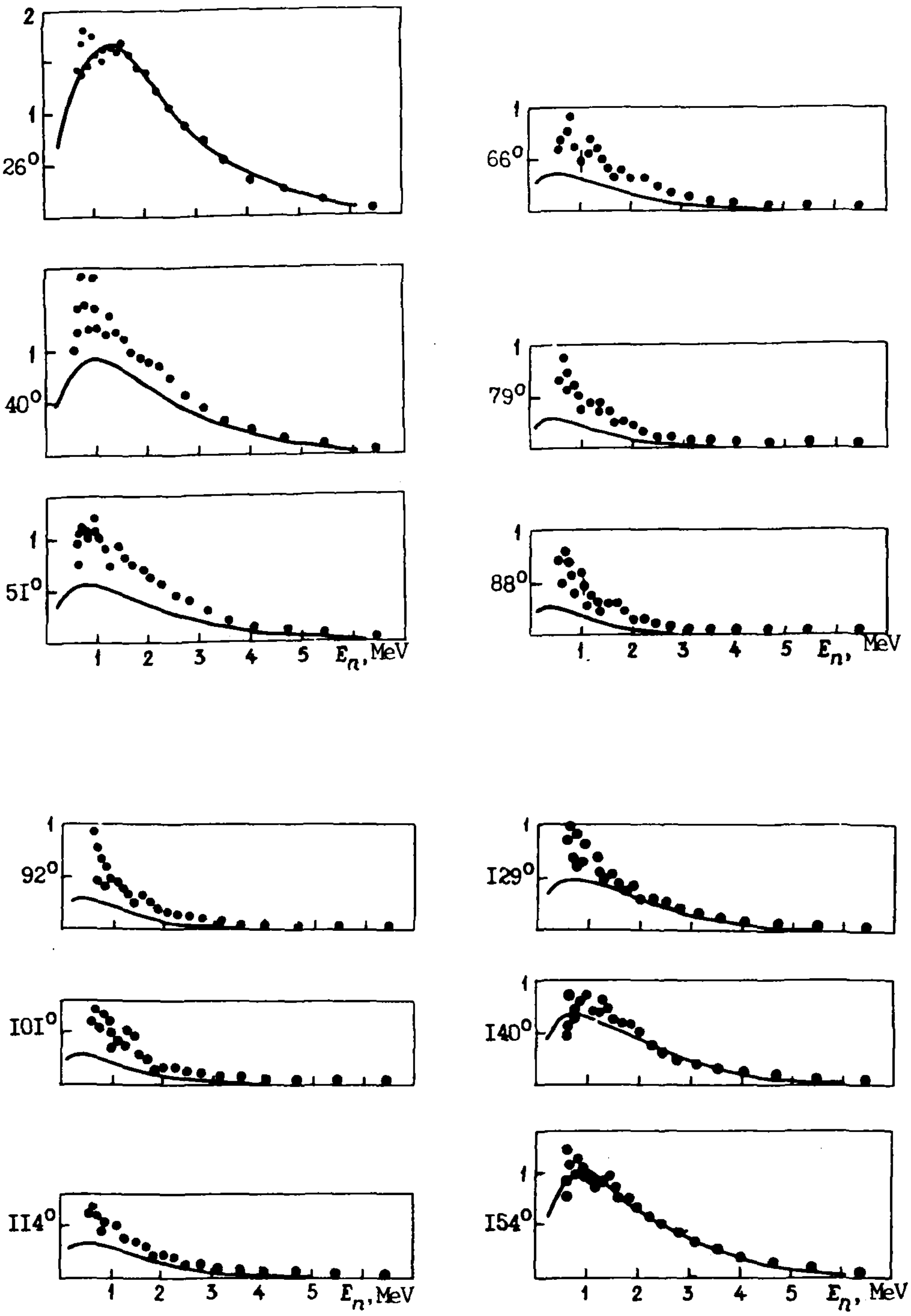
Table.

Range No.	No. of fissions	$\bar{M}_H$ amu*	$\bar{E}_{t.k.}$ MeV
1	78 852	132.6	181.6
2	111 244	132.6	200.3
3	294 260	144.2	173.9
4	646 539	142.8	189.8
5	87 383	140.8	204.9
6	120 635	154.2	172.0
7	73 678	153.3	186.9
8	1 414 251	143.1	186.1

* 1 amu ≈ 1.66057×10^{-27} kg.



Neutron spectra at $\bar{\theta}^{o}$ to the direction of motion of light fragments (range 5); $\bar{M}_H$ = 140.8 amu; $\bar{E}_{t.k.}$ = 204.9 MeV; ɸ = experiment; the solid curves represent the results predicted according to the theory of isotropic neutron evaporation from all the accelerated fragments.