Analysis of Fragment Mass Distribution in Asymmetric Area at Fission of $^{235}$U Induced by Thermal Neutrons*

V. P. Pikul$^{1)}$, U. Yu. Jovliev$^2)$, Yu. N. Koblik$^1)$, A. V. Khugaev$^1)$, A. I. Muminov$^2)$, A. K. Nasirov$^{2), 3)}$, K. V. Pavliy$^2)$, and B. S. Yuldashev$^1)$

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Abstract—The fragment mass yields in fission of $^{235}$U induced by thermal neutrons for $A = 145–160$ and $E_K = 50–75$ MeV were measured using a mass spectrometer. The line structure is observed at $A = 153$, 154 and $E_K = 50–60$ MeV. The obtained results were described in the framework of a model based on the dinuclear system concept. The analyzed correlation between the total kinetic energy and mass distribution of fission fragments is connected with the shell structure of the formed fragments of fission. From this correlation and the time dependence of the calculated mass distribution of the binary reaction products, one can conclude that the descent time from a saddle point to a scission point for the more deformed fragments is longer than that for fragments of more compact shape.

1. INTRODUCTION

The complete understanding of the nuclear fission mechanism and dynamics of mass distribution is yet to be achieved. Nuclear fission is one of the most complex nuclear transformations, related to a strong change of compound nucleus shape, leading to formation of two or three (ternary fission) fragments having an excitation energy that is sufficient for emission of several neutrons and γ quanta. It is difficult to obtain complete information reflecting the dynamics of fission processes during experiment. The process of fission allows us to observe a nucleus of abnormally high deformation and large surplus of neutrons, which opens opportunities of research of such properties of the nucleus as collective movement with large amplitude, strength functions of β decay, and viscosity and friction of a nuclear matter.

The exploration of mass and charge distributions of fission fragments and their kinetic energy is an important task in the analysis of the fission process. In Section 2, we present and discuss the results of measurements of mass and kinetic energy distributions of the fission products of $^{235}$U. Section 3 is devoted to the calculation of the mass distribution between fragments of fission in the framework of the dinuclear system model. In Section 4, the theoretical and experimental results are compared and discussed. Conclusions are in Section 5.

2. EXPERIMENT

We carried out measurements of mass ($A$) and kinetic energy ($E_K$) distributions of the heavy fission products of $^{235}$U in a region where there are not enough experimental data, namely, $A = 150–160$ and $E_K = 50–75$ MeV. Measurements were performed using an electromagnetic mass spectrometer for the unslowed fission products [1]. It was placed on the horizontal channel nuclear reactor VVR–SM of the Institute of Nuclear Physics of the Academy of Sciences of Uzbekistan. The accuracies of measurements of kinetic energy and mass of fission products were equal to 0.02 and 0.06%, respectively.

Mass distributions of the heavy products with kinetic energies $E_K = 50, 55, 60, 65, 70$, and $75$ MeV, which were measured in fission of $^{235}$U induced by thermal neutrons [2], are presented in Fig. 1. The structure at $A = 144–146$ in the range $E_K = 50–60$ MeV (Fig. 1) is, most likely, connected to large probability of formation of complementary light fragments with $A = 90–92$ [2]. The contour diagrams of the shell corrections, which are designed on the Wilkins model [3], show (Fig. 2) that there are areas with the minima of the potential energy corresponding to the small deformations of fragments with the magic numbers $Z = 50$ of protons and $N = 50, 82$ of neutrons and to the large deformations $\beta = 0.6–0.7$ of fragments with the proton numbers $Z = 40, 44$ and the neutron numbers $N = 66, 88$ of fission fragments.

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1) Institute of Nuclear Physics, Tashkent, Uzbekistan.
2) Heavy-Ion Physics Department, Institute of Nuclear Physics, Tashkent, Uzbekistan.
3) Bogolyubov Laboratory of Theoretical Physics, Joint Institute for Nuclear Research, Dubna, Moscow oblast, 141980 Russia.
Assuming $D = c_1 + c_2$, we can find the shape of fragments at the scission point. The deformation parameter of fragments was calculated using the expression

$$
\beta = 1.05(c_i - a_i) / (a_i^2 c_i)^{1/3},
$$

where $c_i$ and $a_i$ are the large and small axes of ellipse, respectively.

The mass yields of fragments in fission of $^{235}$U induced by thermal neutrons were calculated in [3] as a function of the distance between centers of fission fragments at the scission point. Two-dimensional contour diagrams of these dependences have been constructed. In these contour diagrams, the correlation between the distance $D$ and different values of TKE (Fig. 2) can be established. Rather good agreement between the mass yields measured by us and calculated using the Wilkins model [3] is observed. The large probability of formation of fission fragments with $A = 146$–150 with relatively low kinetic energies is connected with the increase in the shell corrections for deformation parameters $\beta = 0.6$–0.7, which corresponds to the distance between centers of fragments $D \approx 17$ fm (Fig. 2), because the values of TKE for the given pair of fragments are defined by their deformation parameters $\beta$ at the scission point.