NEW SIDE OF THE COLLINEAR CLUSTER TRI-PARTITION SCENARIO

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INTRODUCTION

In our previous publications we discussed different manifestations of a new decay channel of the low excited heavy nuclei called collinear cluster tri-partition (CCT) [1–4]. The most populated CCT mode was revealed in the mass correlation distribution of fission fragments (FFs) as a local region ("bump") of increased yields below the loci linked to the conventional binary fission. The bump was dubbed the "Ni-bump" because it is centered at the masses associated with the magic isotopes of Ni. The bulk of the results has been obtained by using the "missing mass" approach. It means that two decay products (fragments) are detected in coincidence using a double armed time-of-flight spectrometer, while the significant difference between their total mass $Ms = M_1 + M_2$ and the mass of a mother system serves as a sign of at least ternary decay. Mainly a scattering of fragments at the entrance of an *E*-detector gives background events simulating ternary decay. Observation of the specific linear structures in the M_1–M_2 distributions (mass correlation plots) served as a criterion for a sufficient suppression of the background. Analysis of the fission events from the "Ni-bump" allowed us to draw a conclusion that the ternary fission observed should be treated as "almost sequential", but it is very close to the sequential one [4]. Hear we present our new experimental result that decisively confirms this conclusion.

EXPERIMENT

The experiment was performed at the beam of the MT-25 microtron, FLNR, JINR, using VEGA (V-E Guide based Array) setup. The scheme of the spectrometer is shown in Figure 1.

Fission fragments (FFs) from the ^{235}U (γ, *f*) reaction in the target (1) is captured by the electrostatic guide system (EGS) consisted of the tube (2) and the central wire (3). The FF energy *E* and velocity *V* required for calculation of the FF mass are measured in the time-of-flight spectrometer consisted of the microchannel-plates based timing detector (4) and the mosaic of four PIN diodes (5).

Presence of the EGS is a principal difference between VEGA setup and other time-of-flight spectrometers used in our experiments earlier. The EGS constitutes a cylindrical capacitor with a thin wire as a central electrode. Some part of the ions emitted from the target at one end of the guide can be involved in the spiral-like movement along the guide axis thanks to the radial electric field, which dims the radial component of the ion velocity. According to [5], where the EGS was proposed for the first time, the collection efficiency *Fc* of the guide for an extended uniform target of radius b, equal to the tube (outer cylinder) radius R, is estimated to be:

$$Fc = 0.153qV0/ \{Eff \ln(R/s)\}, \quad (1)$$

where $V0$ – is the potential difference between the two conductors,
Eff – is the kinetic energy of the fission fragment,
s – is the radius of the central wire of the guide,
q – is the ionic charge of the fragment.

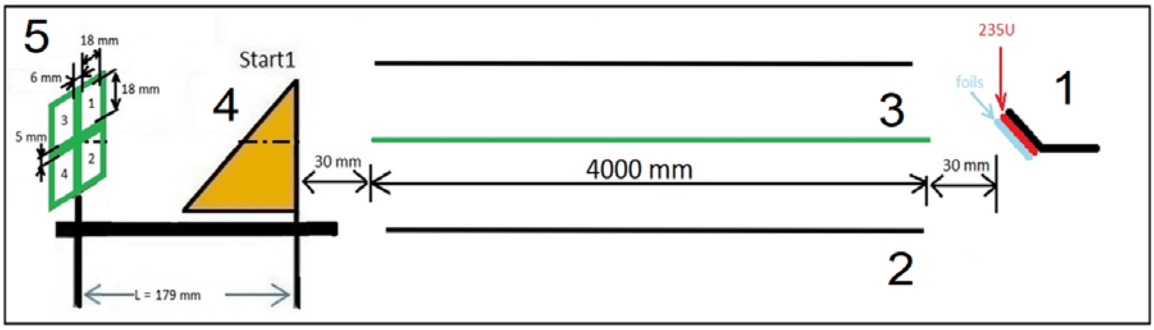

FIGURE 1. The scheme of the VEGA setup. Target (1) of ^{235}U isotope is irradiated by brake gamma quanta of the electron beam of the MT-25 microtron. Some fraction of the fission fragments is captured by the electrostatic guide system (EGS) consisted of the tube (2) at zero potential and the central wire (3) at a potential – 6 kV. At the exit of the EGS, the FF energy E and velocity V for calculation of the FF mass are measured in the time-of-flight spectrometer consisted of the timing detector (4) and mosaic of PIN diodes (5). The main dimensions are marked in the figure.

For instance, for the ion of ^{52}Ca with E_{ff} = 57 MeV and ionic charge q = 4 the maximum angle of capture β_{max} is about 1^0 in the EGS, with the following parameters: V_0 = 10 kV, R = 56 mm, s = 0.1 mm, target diameter d = 5 mm.

According to Eq. (1), only minor part of the ions already caught in the guide will be lost along the flight-pass even if it is very long. Thus, the EGS allows to increase a counting rate at the detector placed few meters away from the target. A spectrometer with extremely long flight-pass is also useful for estimating of the shape isomers' lifetime lying even in the microsecond range [6].

We planned to use the EGS for transporting the FFs from the target in the vicinity of the IBR-2 reactor (FLNP, JINR) active zone to the detectors placed several meters from the target [7]. Similar guide system has been already used at the vertical reactor channel [8]. Due to the technical problems finally the project VEGA was realized at the beam of the microtron MT-25.

RESULTS

The mass correlation distribution for the FFs detected in coincidence in two different PIN diodes of the mosaic (Figure 1) is presented in Figure 2.

Some structures inside the box w1 (Figure 2a) attract attention. This region is shown on a larger scale in Figure 2b. Solid lines (1–4) match the expression $M_1 + M_2$ = const. Likely there are two lines (5, 6) approximately perpendicular to them, and some points are grouping around the line (7) M_2 = const = 12 u. Earlier, similar linear structures were observed for the FFs from $^{252}Cf(sf)$ [2]. Concentration of points (8) is seen around $M_1 \approx 130$ u. The origin of the lines (1, 2) is discussed below while treating of other mentioned peculiarities are beyond the scope of the present paper.

The fission events constituting the lines (1, 2) are characterized by the following mean values of energies and velocities: $\langle E_1 \rangle \approx 64$ MeV, $\langle E_2 \rangle \approx 3$ MeV, $\langle V_1 \rangle = 0.96$ cm/ns; $\langle V_2 \rangle = 0.43$ cm/ns.

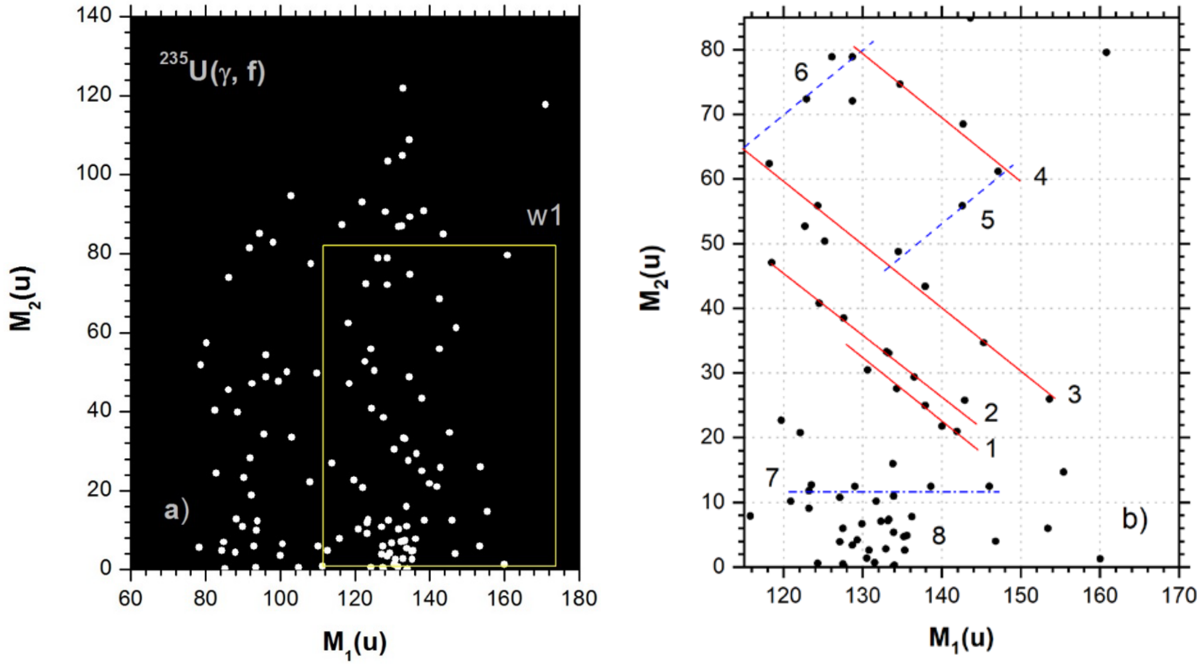

FIGURE 2. Mass correlation distribution for the FFs detected in coincidence in two different PIN diodes (a) and its part from box *w*1 (b).

DISCUSSION

The lines (1, 2) in Figure 2b correspond to the missing masses 72 u and 68 u respectively. These masses are associated with magic isotopes of ^{72}Ni and ^{68}Ni. In our previous experiments at the double-armed time-of-flight spectrometers FOBOS and COMETA just these fragments manifested themselves as "Ni-bump" [1, 2]. The region of the Ni-bump in the FFs mass correlation distribution is presented in Figure 3.

Kinematical analysis of the events from the Ni-bump [4] allowed us to suppose that the prescission configuration leading to the ternary decay looks like the one shown in Figure 4. The events forming peaks in Figure 3b are predominantly due to the nucleus shape shown in Figure 4b and the first rupture is supposed to occur in the vicinity of the surface of Sn cluster. Deformation energy of the light nascent fragment of Cd is enough for its fission with formation of Ni nucleus as one of the decay products. Thus, the ternary sequential decay (CCT) takes place. Ni-bump is observed also in the FFs mass correlation distribution from the reaction $^{235}(n_{th}, f)$ [1] and the prescission configurations similar to those shown in Figure 4 could be decisive for its appearance.

Keeping in mind all said above, the following scenario for the events constituting the lines (1, 2) in Figure 2b could be proposed. Binary fission of the excited ^{235}U nucleus in the prescission configuration similar to that shown in Figure 4a occurs, with formation of Ni nucleus as the light fragment. The fragment stops in the target backing, while the heavy fragment which is flying in the opposite direction is caught into EGS (Figure 1). After approximately 400 ns ($\langle V_1 \rangle \approx 1$cm/ns and the EGS length is about 400 cm) the heavy fragment reaches the start detector where its brake-up in very thin foil (50 μg/cm^2 of Al_2O_3)

occurs. The main conclusion which can be drawn from the result under discussion is that ***the heavy fragment of photo-fission of ^{235}U nucleus is born in the shape isomer state and the life time of this state exceeds 400 ns.*** The result was obtained for the first time.

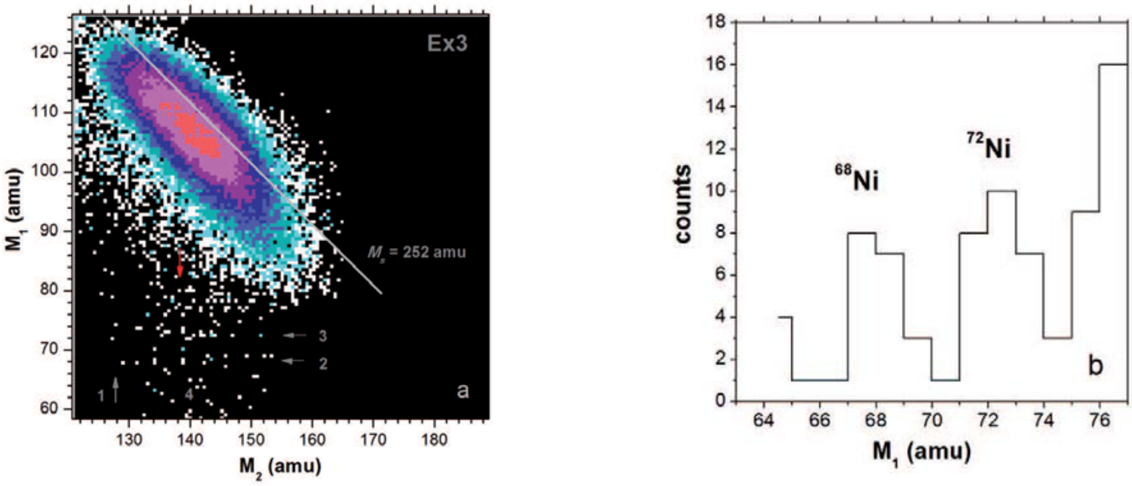

FIGURE 3. The region of the "Ni-bump" in the mass correlation distribution of the FFs from ^{252}Cf(sf) measured using COMETA setup (a). Projection of the bump onto the M_1 axis (b). It should be noted that this figure was published in Ref. [2].

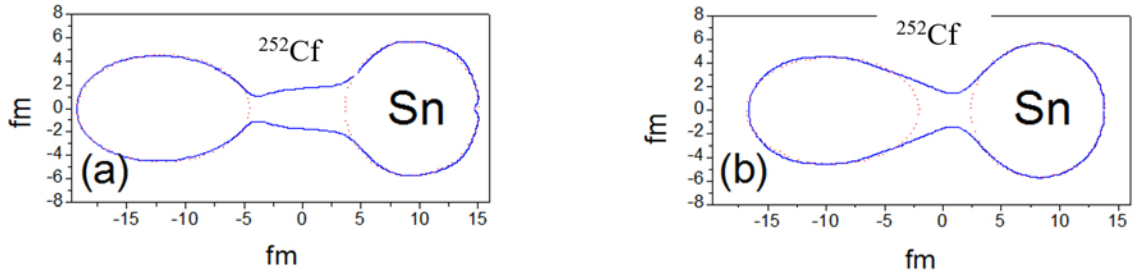

FIGURE 4. Shapes of the fissioning ^{252}Cf nucleus for large system elongations in two different fission valleys [4, 9].

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