NEW RESULTS IN STUDIES OF THE SHAPE ISOMER STATES IN FISSION FRAGMENTS

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INTRODUCTION

In our previous publications [1–5] we have discussed the manifestations of a new original effect appeared at crossing of the metal foils by fission fragments. We have observed significant mass deficit in the total mass M_s of the fission fragments detected in coincidence with ions knocked out from the foil. It was shown that at the large angles of scattering of the knocked–out ions from the foil predominantly conventional elastic Rutherford scattering takes place. As the result M_s corresponds to the mean mass of the mother system after emission of fission neutrons (no missing mass). In contrast, in near frontal impacts fission fragment misses essential part of its mass. More detailed information concerning the effect under study was obtained in our recent experiment discussed below.

EXPERIMENTS AND RESULTS

The experiment was performed at the LIS (Light Ions Spectrometer) spectrometer in FLNR of the JINR. The layout of the setup is shown in fig. 1. LIS is a double-armed time-of-flight spectrometer which includes three micro-channel based timing detectors and two PIN diodes. Each PIN diode provides information for estimating both FF energy and time-of-flight. Metal foils (degraders) of different thicknesses can be placed in the detector TD1. The aperture for fission fragments detected in coincidence in the opposite PIN diodes does not exceed 3^0. The data acquisition system consists of the fast digitizer CAEN DT5742 and a personal computer. The digital images of all the signals were obtained for further off-line processing. Mass reconstruction procedure used is presented in [6]. The construction of the spectrometer allows measuring of fission fragment (FF) mass using “two-velocities” (using time-of-flights at the bases L3and L4) and “velocity-energy” (using time-of-flight at the base L5 and energy measured by PIN1) approaches simultaneously. Corresponding mass values will be marked below M_{tt} and M_{te}. Thus, we know the mass of each FF before and after it crosses the degrader-foil in TD1.

Mass correlation distribution M_{tt}–M_{te} obtained for the heavy FFs mass peak is presented in fig. 2. Copper foil 4.11 microns thick was placed in the TD1detector. Pronounced grid-like structure is vividly seen. Projection of the plot onto M_{te} axis is shown in fig. 3a. For the comparison – earlier measured [3] mass spectrum of the fragments detected in coincidence with the ions knocked out from the foil and in the same arm with them is shown in fig. 3b.

$M_{tt} = M_{te}$ distributions below the loci of conventional binary fission also demonstrate linear structures (fig. 4).

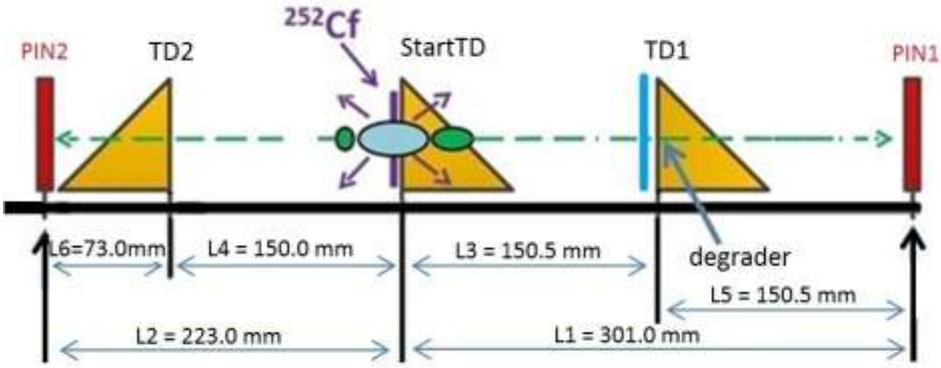

FIGURE 1. Layout of the LIS spectrometer which includes three timing detectors (StartTD, TD1, TD2), two PIN diodes and ^{252}Cf (sf) source. Additional metal foil (degrader) can be placed in TD1 detector.

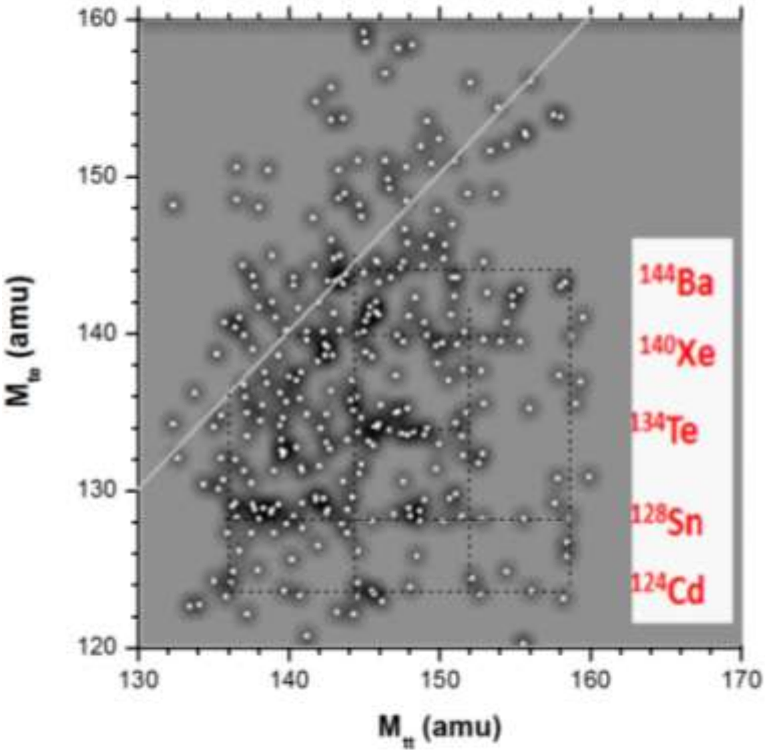

FIGURE 2. Mass correlation distribution M_{tt}–M_{te} for the heavy FFs mass peak. Copper foil 4.11 microns thick was placed in the TD1detector. Dotted lines are drawn to guide the eye. Horizontal lines correspond to known spherical and deformed magic nuclei. Tilted white line corresponds to the equation $M_{tt} = M_{te}$.

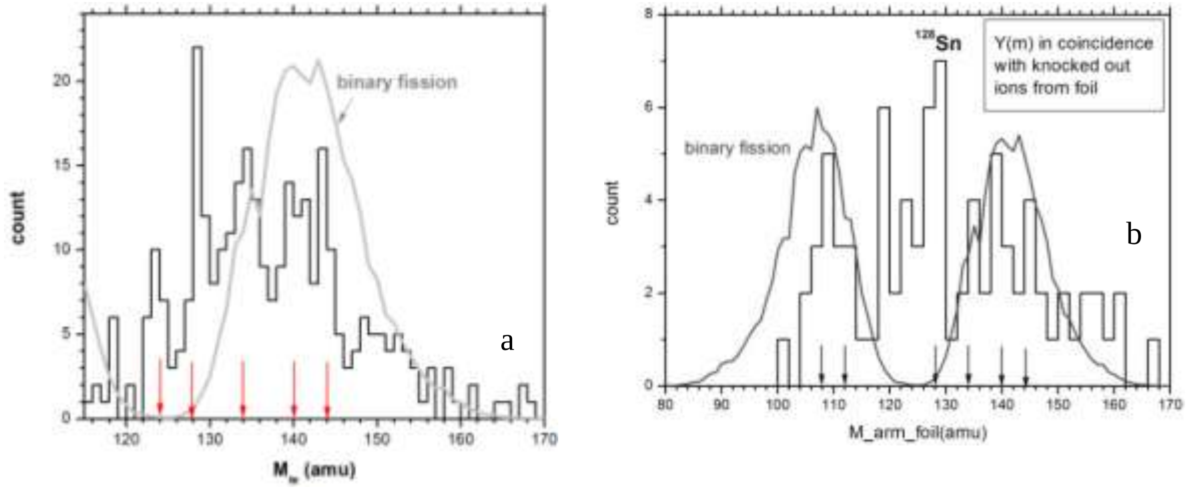

FIGURE 3. Projection of the mass distribution from fig. 2 onto M_{te} axis (a). Masses of known magic nuclei (listed in the panel in fig. 2) are marked by arrows. Mass spectrum of the FFs from conventional binary fission is shown in gray. For comparison: – mass spectrum of the fragments detected in coincidence with the ions knocked out from the foil and in the same arm with them (b) [3].

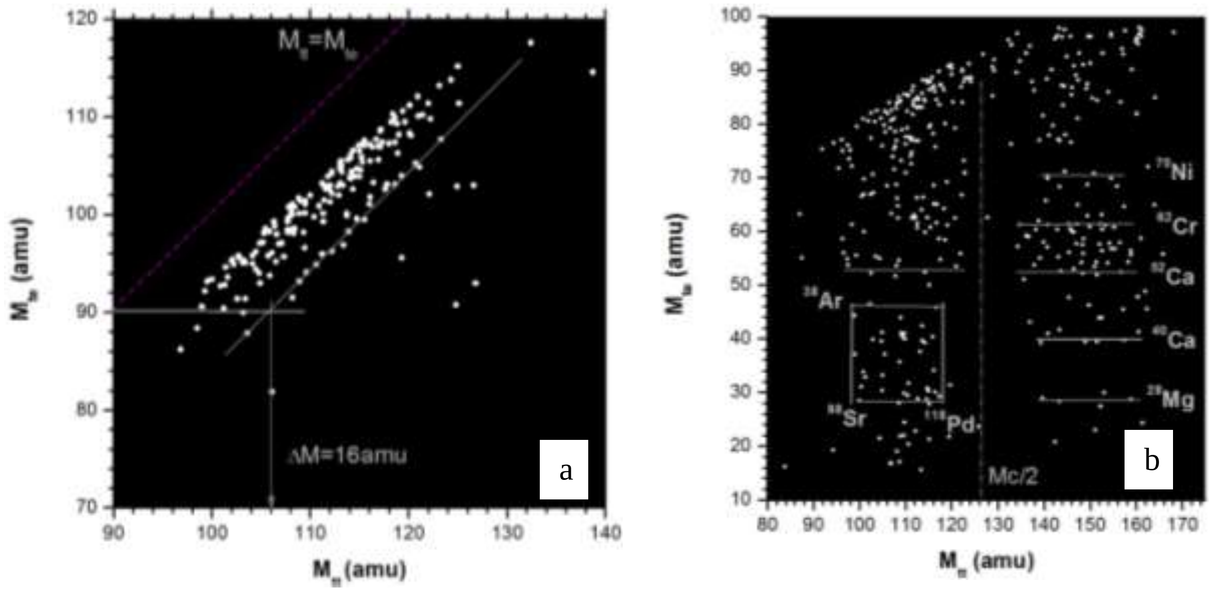

FIGURE 4. Linear structures below the loci of conventional binary fission. Tilted line corresponds to the missing mass 16 amu for the FFs in the light mass peak (a); b – linear structures assosiated, predominantly, with magic nuclei (horizontal lines are drown to guied the eye).

DISCUSSION

The mass distribution in fig. 2 vividly shows event by event how changes the initial mass M_{tt} of the heavy fragment after passing of the foil. Full distribution consists of two parts, namely FFs crossed the foil without missing mass and those which lost part of their masses. Both parts are almost equal by number of events in specific conditions of this experiment. The result observed corresponds to the hypothesis that initial fragment consists of one of the magic cores (listed in the inset in fig. 2) [7] and additional nucleons adding the mass of the core up to the total mass of the fragment. These additional nucleons are missed due to inelastic scattering of the initial fragment in the foil. Projection of the plot onto M_{te} axis (fig.

3a) differs radically from the mass distribution of heavy fragments in conventional binary fission. The strongest difference is observed for the masses associated with magic isotopes of ^{128}Sn and ^{124}Cd. The spectrum in fig. 3a agrees well with this shown in fig. 3b obtained earlier [3]. The latter spectrum can be call the spectrum of "brake-up residuals" detected in coincidence with a nucleus knocked out from the foil in the same spectrometer arm.

The question arises what is actually the fragment before passing of the foil? We have supposed [2] it looks like certain di-nuclear system consisting of magic core and light cluster. It could be shape-isomer state of the fragment. The mean flight-time of heavy FF on the flight path L3 (fig. 1) does not exceed 15 ns. This value can be adopted as a low limit of a life-time of typical shape-isomer state in the fission fragments.

Mass distributions in fig. 4 provide additional information concerning clustering in the FFs. Below the bottom edge of the locus of the light FFs (fig. 4a) we see the group of events showing fixed difference $\Delta M = M_{tt} - M_{te} = 16$ amu. In other words, some part of the FFs of the light mass peak loses, presumably, ^{16}O nucleus when passing the degrader. Fig.4b shows directly that there are a lot of other light nuclei becoming the products of the brake-up of the FFs in the metal foil. Our previous results give an idea concerning the origin of these light fragments. We have observed specific tilted ridges $M_s = M_1 + M_2 = \text{const}$ in the frame of the so called "Ni-bump" [8, 9] of the correlation FFs mass distributions (fig. 5). The ridges are linked with missing light fragments with following mass numbers: 38, 40, 44, 48, 50, 56. Let's consider two examples for illustrating the idea concerning the link between the distributions in fig. 4b and fig. 5.

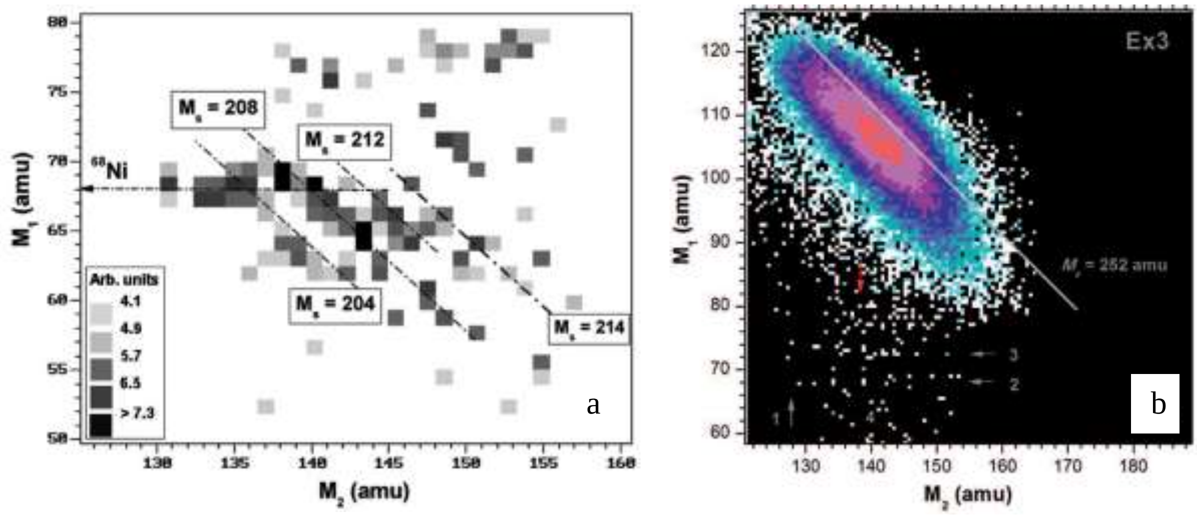

FIGURE 5. Linear structures $M_s = M_1 + M_2 = \text{const}$ in the frame of the "Ni-bump" of the correlation FFs mass distribution from ^{252}Cf(sf) [8,9] measured at FOBOS (a) and COMETA (b) spectrometers.

The horizontal line corresponding to $M_{te} = 52$ amu (presumably ^{52}Ca) in fig. 4b starts from $M_{tt} = 134$ amu (presumably ^{134}Te). The following prescission configuration could correspond to this "starting" point:

$$^{118}Pd - \underbrace{\boxed{^{82}Ge - {}^{52}\mathbf{Ca}}}_{^{134}Te} . \qquad (1)$$

Di-nuclear system ^{82}Ge – ^{52}Ca undergoes a brake-up when passing the foil. Due to kinematics and PIN1 (fig. 1) aperture only ^{52}Ca ion is detected in this spectrometer arm while ^{82}Ge is missed. The mass of the heavy initial fragment (^{134}Te) can increase thanks to the nucleons coming from the light initial fragment (^{118}Pd) but in any case ^{52}Ca stays one of the constituents of the di-nuclear system. The scenario presented is similar to this standing behind the ridges M_s = const in fig. 5.

Similar scenario is realized as well in the light FFs mass peak. For instance,

$$ {}^{154}Nd - \underbrace{{}^{52}Ca - {}^{46}\mathbf{Ar}}_{{}^{98}Sr} \; . \qquad (2) $$

CONCLUSIONS

1. New confirmation of the binary brake-up of the fission fragments when passing of metal foil was obtained.
2. In the light of the results obtained fission fragment is supposed to be born in the shape isomer state which looks like di-nuclear system consisting of the magic core and lighter cluster.
3. A low limit of a life-time of typical shape-isomer state in the fission fragments is estimated to be 15 ns.

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