Observation of cluster structure of fission fragments

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Abstract. The manifestation of a new original effect appearing at crossing of the metal foils by fission fragments is reported. The effect takes place predominantly at front impacts. The obtained results suggest that a fragment from conventional binary fission is born in shape-isomer state which looks like a di-nuclear system with magic core.

1. Introduction
In our previous experiments [1, 2] at the COMETA setup we observed essential mass deficit in the total mass of the fission fragments detected in coincidence with the ions knocked out from the metal foil. The brake-up takes place predominantly in the frontal impacts. Such effect could be expected if the scattered fragment looks like a di-nuclear system destroying due to inelastic scattering on the nucleus of the foil. Further experiments discussed here are dedicated to event by event “weighing” of the fragment before and after the foil. 

2. Experiments and results
The experiments were performed at the LIS (Light Ions Spectrometer) spectrometer in the FLNR, JINR. The layout of the setup is shown in figure 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 30'. A data acquisition system consists of the fast digitizer CAEN DT5742 and a personal computer. The digital images of all the signals are obtained for further off-line processing. The construction of the spectrometer allows measuring of the FF mass using “two-velocities” (time-of-flights at the sections L3 and L4) and “velocity-energy” (time-of-flight at the section L5 and energy measured by PIN1) methods simultaneously. Corresponding mass values will be marked below with $M_t$ and $M_e$. Thus, we know the mass of each FF before and after it crosses the degrader-foil in TD1.

Here we compare the results of two experiments carried out at the LIS setup. They differ by the applied time-pickoff algorithms. Well known CFD (Constant Fraction Discriminator) method gives a
time-pickoff point which is independent from the amplitude of the signal but is biased comparing to “true” moment when the ion hits the detector. The delay is due to the “plasma delay” effect in the PIN diode and should be taken into account using special parametrization. Mass reconstruction procedure based on CFD method [3] was used in the experiment Ex1. In order to have a “true” time pickoff point, we had proposed “sewing parabola time-pickoff” method [4] which was applied in Ex2.

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

The mass distributions in figure 2 show event by event how the initial mass $M_{tt}$ of the heavy fragment changes after passing the foil. Projections of the plots onto $M_{te}$ axis (figures 2(c) and (d)) differ from the mass spectrum of heavy fragments in conventional binary fission. The strongest difference is observed for the masses associated with magic isotope s of $^{128}$Sn and $^{124}$Cd.

Figure 2. Mass correlation distributions $M_{tt}$-$M_{te}$ obtained for the heavy FFs mass peak are presented in figures 2(a), (b). They were obtained in the experiments Ex1 and Ex2 respectively. Copper foil 4.11 microns thick was placed in the TD1 detector. Projections of the plots onto $M_{te}$ axis are shown in figures 2(c), (d). Masses of known magic nuclei are marked by arrows. Mass spectrum of the FFs from conventional binary fission is shown in grey. See text for details.
Based on the experimental results obtained so far we suppose that the FF from conventional binary fission is borne in a shape-isomer state. Taking into account the flight-pass between the Cf source and the degrader (figure 1), a typical life time of these states is no less than 15 ns. In the experiments [5] dedicated to the detection of the delayed x-rays from FFs, some emitters were found having life times on the order of microseconds. They are supposed to be shape-isomers. Thus, it is reasonable to expect such long life-times of the FFs isomer states also in our experiments. Very specific shape of the mass spectrum of the FFs passed through the foil (figure 2) could be a criterion that the FF stays in excited shape-isomer state before crossing the foil. Increasing the flight pass we could rich the disappearance of the effect but the expected flight-pass would be some meters long with a huge decreasing of the counting rate. The problem can be solved by using of the electrostatic guide system [6]. In this case the effective aperture stays constant and almost independent from the flight-pass length.

**Figure 3.** Layout of the VEGA-M spectrometer installed in the hall of the MT-25 microtrone of FLNR (JINR) – (a). Right to left: $^{235}$U target in the gammas beam, four meters long electrostatic guide, start MCP based detector, mosaic of four PIN diodes – (b).

This idea is realised by developing the VEGA-M (Velocity-Energy Guide based Array on Microtrone) spectrometer which is aimed to investigate long lived shape-isomer states in fission fragments. It’s installed in the hall of the MT-25 microtrone of FLNR (JINR) (figure 3). The test experiment using VEGA-M setup was carried out recently. The main issue to be solved in the test is the noise reduction in electronics installed inside the experimental hall of the accelerator. Signals from the detectors observed so far have shown that there exists the high frequency interference generated by the accelerator that is not constant along the bunch. In other words there is a part which is free from interference. Thus further investigation of the cluster effects in the FFs from photo-fission are planning.

### 3. Discussion

The most pronounced peculiarity of the $M_{de}$ spectrum observed in Ex1 (figure 2(c)), namely strong peaks at the mass numbers 124 and 128 was reproduced well in Ex2 (figure 2(d)). At the same time, the mass correlation distribution from Ex2 shows some new interesting details. Corresponding structures are marked by the numbered arrows (1-8). The vertical lines $M_{de} = (134, 136, 130)$ amu attract attention. Currently we do not know the nature of these structures. Horizontal lines (3-5) are associated with the magic nuclei of $^{136}$Xe and $^{144}$Ba. The lines that intersect the diagonal $M_{de} = M_{int}$ and lie in the region to the left of the diagonal seem to be methodical artefacts. As an alternative interpretation these structures may result from the process of nucleon transfer that takes place from the degrader to the flying fission fragments until they become magic nuclei. Similar effect may cause formation of locus (6). Loss of some mass by the fragments passing the foil explains the tilted lines (7, 8) linked to the missing clusters of $^{32}$Mg and $^{38}$Si respectively.

### 4. Conclusions

Our previous results observed at COMETA setup have been confirmed by the new data obtained recently at LIS spectrometer using the modified experimental method: fission fragments from conventional binary fission at least during 15 ns after fission manifest themselves as shape-isomers.
By passing through the metal foil fission fragments undergo a brake-up with formation of a magic nucleus as one of the brake-up product.

Our nearest plans are connected with the experiments at the microtrone using VEGA-M setup. The experiment is aimed to estimate the FFs shape-isomer life times in the microsecond range.

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