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## Observation of shape isomers states in fission fragments

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**Abstract.** We discuss 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  $M$  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  $M$  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. Residual nuclei at least for the fragments from the heavy mass peak show magic nucleon composition.

### 1. Experiments and results

The layout of one of the experiments (marked below Ex1) dedicated to passing of the fission fragments (FFs) through the metal foils [1–4] is presented in figure 1. The geometry of the source unit is shown in detail in figure 1a. Absorber foil was placed at 1 mm distance from the Cf source. Typical FF overcomes such distance approximately in 0.1 ns. Ternary events were analyzed. It means that three fragments were actually detected in coincidence in three different silicon detectors. For the sake of convenience, the FFs from such events are labeled as  $M_1$ ,  $M_2$  and  $M_3$  in an order of decreasing masses in the ternary event. Mass distribution for ternary events is shown in figure 2. The total mass of the two heavier fragments  $M_1+M_2$  is plotted vs. the mass of the lighter fragment  $M_3$ . As can be inferred from the figure almost in all the events where the lightest fragment corresponds to the knocked out Cu ions ( $M_3$  is around 64 amu, figure 2a) we observe missing mass of FFs. Similar results were also obtained using Ti and Ni foils.

The effect of Rutherford scattering accompanied by the loss of the mass of the scattered fission fragment takes place also in scattering on  $^{16}\text{O}$  and  $^{27}\text{Al}$  nuclei from the source backing. At the same time at least some part of the FFs scattered on the  $^{12}\text{C}$  nuclei from the organic foil undergo scattering without the mass loss. Corresponding events are marked by the arrow.

Next very interesting result obtained is presented in figure 2b. It is the mass spectrum of the fragments scattered in the foil and detected in coincidence with the knocked out ions. As can be inferred from the figure this spectrum radically differs from the FF mass distribution in conventional binary fission. The masses of known magic nuclei are marked in the figure by the arrows. The most



pronounced peak in the experimental mass spectrum corresponds to the magic  $^{128}\text{Sn}$  nucleus in contrast with the mass yields in conventional binary fission.

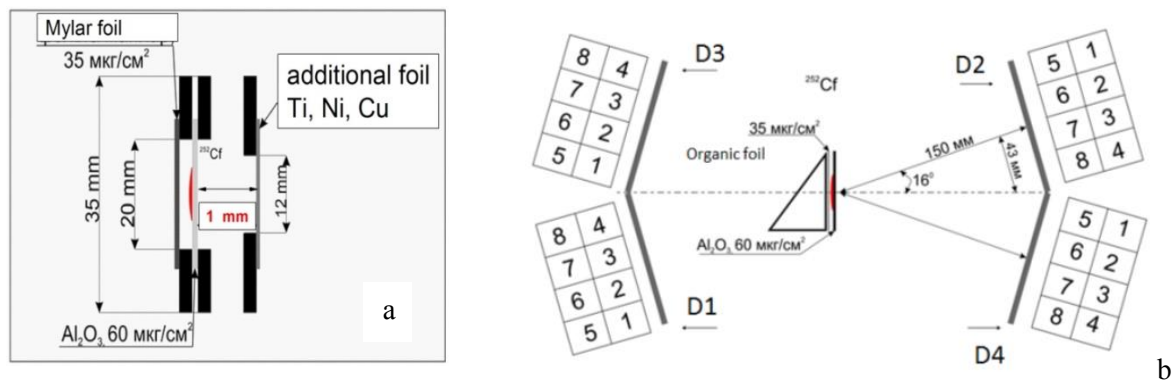


Figure 1. Layout of the experiment Ex1.  $^{252}\text{Cf}$  source and additional foils placed around (a) and positions of the detectors used (b). Micro-channel-plate based start timing detector is placed in the center of the setup while four mosaics eight PIN diodes each provide measuring both FF time-of-flight and energy.

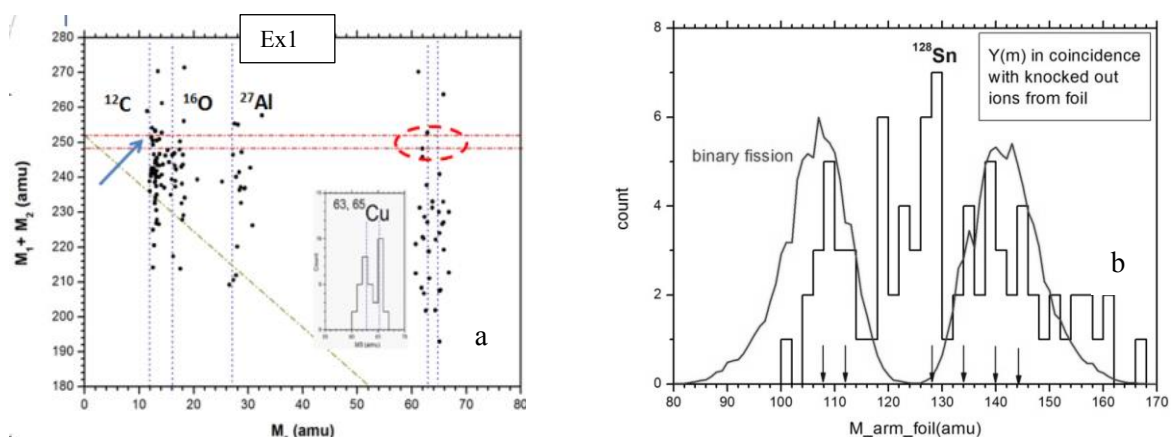


Figure 2. Results for ternary events from Ex1. Cu foil  $0.83\ \mu\text{m}$  thick was used as the additional absorber (a). Mass spectrum of the fragments detected in coincidence with the ions knocked out from the foil and in the same arm with them (b). See text for details.

Additional information concerning the effect under study was obtained in the experiment Ex2. The experiment was performed at the LIS (Light Ions Spectrometer) spectrometer in FLNR of JINR. The layout of the setup is shown in figure 3. 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  $3^\circ$ . 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 [5]. The

construction of the spectrometer allows measuring of the FF mass using “two-velocities” (using time-of-flights at the bases L3 and 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.

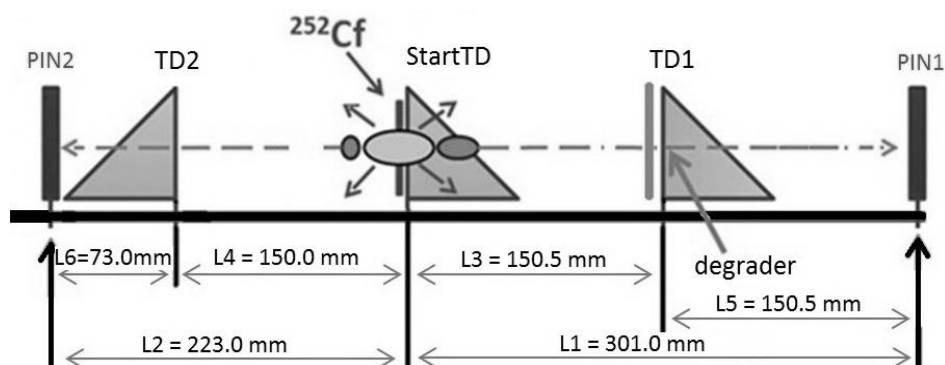


Figure 3. Layout of the LIS spectrometer used in Ex2. It includes three timing detectors (Start TD, TD1, TD2), two PIN diodes and  $^{252}\text{Cf}$  (sf) source. Additional metal foil (degrader) can be placed in TD1 detector.

Mass correlation distribution  $M_{tt}$ – $M_{te}$  obtained for the heavy FFs mass peak is presented in figure 4. Copper foil 4.11 microns thick was placed in the TD1 detector. Pronounced grid-like structure is vividly seen. Projection of the plot onto  $M_{te}$  axis is shown in figure 4b. The spectrum agrees well with this obtained earlier in Ex2 (figure 2b).

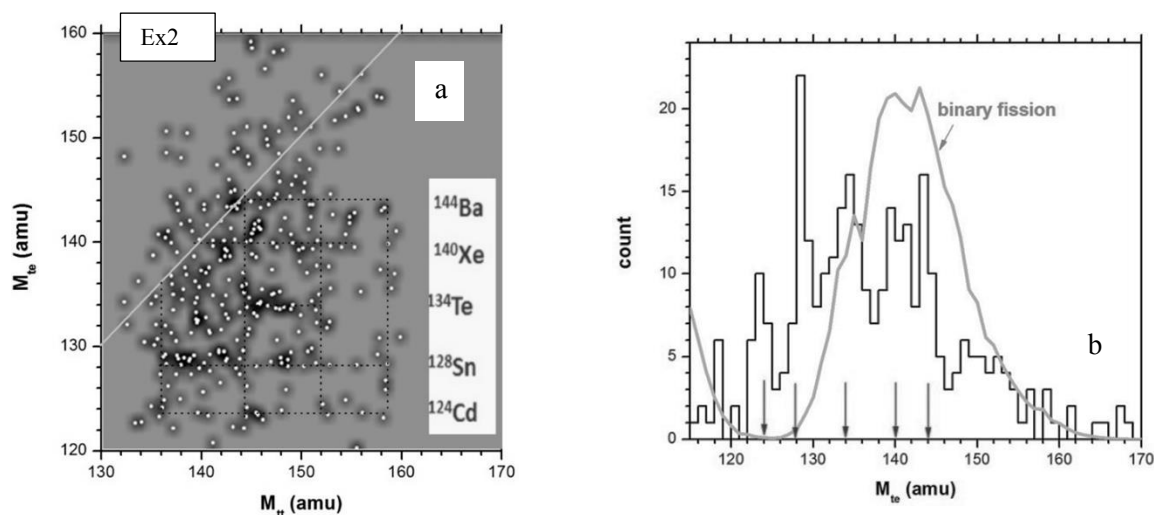


Figure 4. Mass correlation distribution  $M_{tt}$ – $M_{te}$  for the heavy FFs mass peak (a) obtained in Ex2. Copper foil 4.11 microns thick was placed in the TD1 detector. Dotted lines are drawn to guide the eye. Horizontal lines correspond to known spherical and deformed magic nuclei. Tilted white line corresponds to the equation  $M_{tt} = M_{te}$ . Projection of the shown mass distribution onto  $M_{te}$  axis (b). Masses of known magic nuclei (listed in the panel in figure 4a) are marked by arrows. Mass spectrum of the FFs from conventional binary fission is shown in gray.

## 2. Discussion

The mass distribution in figure 4 vividly shows event by event how changes the initial mass  $M_{it}$  of the heavy fragment after passing 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 figure 4a) 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. Thus, apparently fission fragment is burned in shape isomer state. A life time of the typical FF isomer state is estimated to be more than 15ns (mean FF flight-time at L3 in Ex2). Projection of the plot onto  $M_{ie}$  axis (figure 4b) 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  $^{128}\text{Sn}$  and  $^{124}\text{Cd}$ . The spectrum in figure 4b agrees well with this shown in figure 2b obtained earlier in Ex1. The latter spectrum can be called the spectrum of “brake-up residuals” detected in coincidence with a nucleus knocked out from the foil in the same spectrometer arm.

## 3. Conclusions

1. Experimental evidences of the binary brake-up of the fission fragments when passing of metal foil were obtained for the first time.
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 heavy fission fragments is estimated to be 15 ns.

## Acknowledgments

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## References

- [1] Pyatkov Yu V, Kamanin D V, Alexandrov A A, Alexandrova I A, Kondratyev N A, Kuznetsova E A, Strekalovsky A O, Strekalovsky O V, Zhuchko V E 2014 *Proc. 21<sup>th</sup> Int. Sem. on Interaction of Neutrons with Nuclei*, 20–25 May 2013, Alushta, Ukraine (Dubna) p. 127
- [2] Pyatkov Yu V, Kamanin D V, Alexandrov A A, Alexandrova I A, Kondratyev N A, Kuznetsova E A, Strekalovsky A O, Strekalovsky O V, Zhuchko V E 2014 *FIAS Interdisciplinary Science Series, Nuclear Physics: Present and Future*, ed. W. Greiner (Springer) p. 79
- [3] Pyatkov Yu V *et al.* 2015 *Proc. 22<sup>th</sup> Int. Sem. on Interaction of Neutrons with Nuclei*, 27–30 May 2014, Dubna, Russia (Dubna) p. 83
- [4] Pyatkov Yu V, Kamanin D V, Alexandrov A A, Alexandrova I A, Kondratyev N A, Kuznetsova E A, Strekalovsky A O, Strekalovsky O V, Zhuchko V E, Mkaza N 2015 *Int. Sym. on Exotic Nuclei “EXON-2014”*, 08-13 September 2014, Kaliningrad, Russia, ed. Yu E Penionzhkevich and Yu G Sobolev (World Scientific) p. 383
- [5] D.V. Kamanin *et al.*, *Proceedings of the 21<sup>th</sup> International Seminar on Interaction of Neutrons with Nuclei*, Alushta, Ukraine, 20–25 May 2013. Dubna 2014, p. 107.