PHYSICAL PROGRAM AND STATUS OF THE VEGA PROJECT

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INTRODUCTION

In our previous publications dedicated to the collinear cluster tri-partition (CCT) of the low excited nuclei [1, 2] we have discussed the role of scattering medium in the registration of the CCT products. This decay mode has been called by us “collinear cluster tri-partition” (CCT) in view of the observed features of the effect, that the decay partners fly apart almost collinearly and at least one of them has magic nucleon composition. Briefly, even if initially two CCT partners fly in the same direction perfectly collinearly they get some angular divergence after passing the scattering medium on the flight pass due to the multiple scattering. Thanks to such effect they can be registered independently in the “stop” mosaic detector. Actually even thin backing of the radioactive source provides the observable effect. In order to increase the effect additional absorbers (metal foils) were introduced just after the source at the distance of approximately 1 mm. The layout of one of the experiments performed is presented in fig. 1.

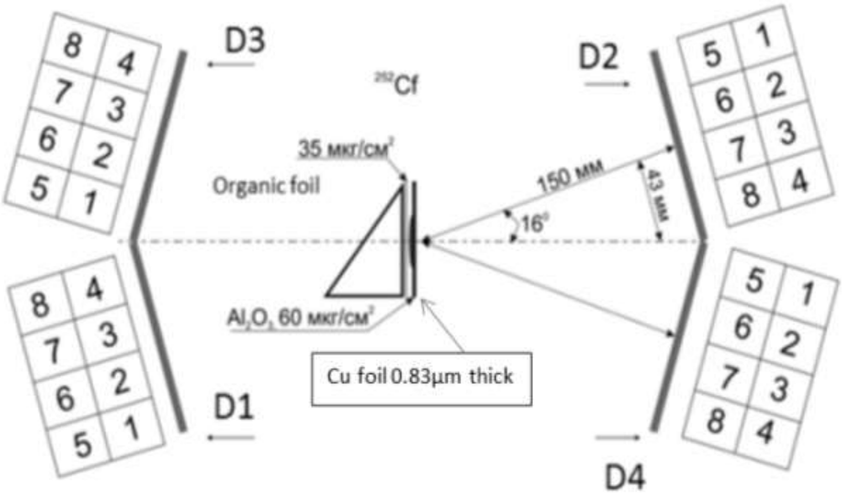

FIGURE 1. Layout of the spectrometer used in the experiments dedicated to the CCT study.

Ternary events were analyzed. It means that three fragments were really 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. The total mass of 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 in almost all the events where the lightest fragment corresponds to the knocked out Cu ions (M3 is around 64 amu) we observe missing mass of fission fragments while the events from the elastic Rutherford scattering should be expected in the region marked by the oval. Similar results were obtained in the series of experiments using different absorbers [3].

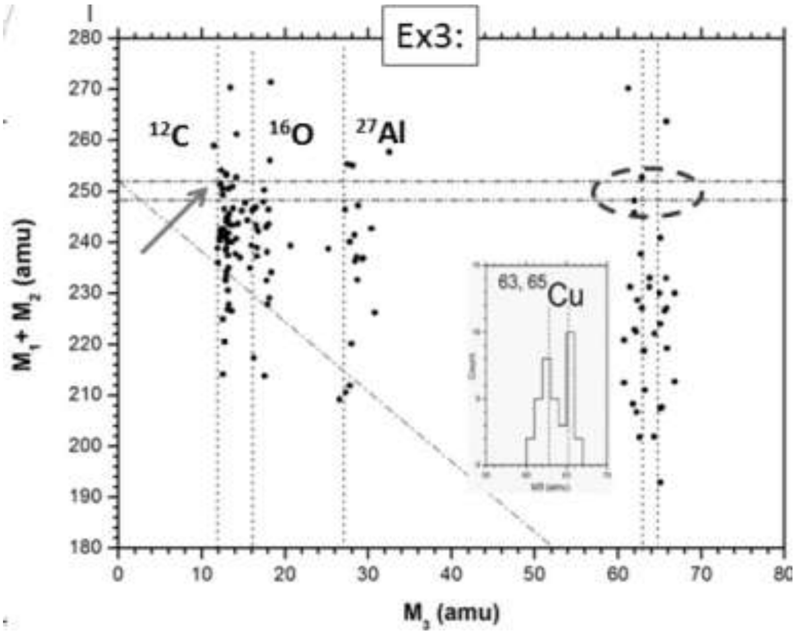

FIGURE 2. Mass distribution for ternary events from Ex3. Cu foil 0.83 mkm thick was used as the additional absorber. See text for details.

The experimental findings allowed us to assume the following:

1. Inelastic impact, at least the frontal one, makes free the constituents of the di-nuclear system (fission fragment) formed in the binary fission.
2. Bearing in mind the distance between the Cf source and the generating foil (~1 mm) the lower limit of the life-time of this di-nuclear system (shape isomer) is about 0.1 ns.
3. Relative probability of elastic Rutherford scattering of fission fragments i.e. taking place without missing mass seems to be much less in our experiments than those in the inelastic channel. In other words, *the bulk of the fragments from the conventional binary fission are born apparently, as shape-isomers.*

Very recent theoretical [4] and experimental [5] results are likely directly connected with our observations which we treat as a manifestation of shape isomeric states in fission fragments.

In new calculations of the potential-energy surfaces as functions of spheroidal, hexadecapole, and axial asymmetry shape coordinates for 7206 nuclei from A = 31 to A = 290 (thus the region of typical fission fragments is included) the authors of [4] identified a lot of nuclei for which a necessary condition for shape isomers occurs, namely multiple minima in the calculated potential-energy surface. In the invers-kinematic experiments at the RIKEN Nishina Center RI Beam Factory fission fragments were selected and identified using superconducting in-flight separator BigRIPS. A total of 54 microsecond isomers with half-lives of ~0.1–10 μs were observed [5] and at least some of them are based on the shape isomeric states.

Naturally the question arises whether we deal with the same shape isomeric states in fission fragments while the deexcitation channel observed is different in our and RIKEN experiments.

MOTIVATION FOR USING OF AN ELECTROSTATIC GUIDE BASED TIME-OF-FLIGHT SPECTROMETER

To answer the question one needs a mosaic time-of-flight spectrometer with extremely long flight-pass for estimating of the shape isomers life time lying presumably in the microsecond range. The layout of the dedicated experiment could be as folowing (Figure 3). Evidently, the geometrical efficiency of the spectrometer would be very low. In order to reach sufficient counting rate at the "stop" detector we are planning to use electrostatic guide [6, 7] at least at the base L1 (fig. 3). Actually electrostatic guide 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 into the spiral-like movement along the guide axis thanks to the radial electric field which dims the radial component of the ion velocity [8]. According to [6] the collection efficiency F_c of the guide for an extended, uniform, target of radius b equal to the tube (outer cylinder) radius R is estimated to be:

$$F_c = 0.153qV_0/\ \{E_{FF}\ln(R/s)\}, \qquad (1)$$

where V_0 – is the potential difference between the two conductors,

E_{FF} – 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.

Only minor part of the ions already cached in the guide according Eq. (1) will be lost along even very long flight-pass (L1 in our case).

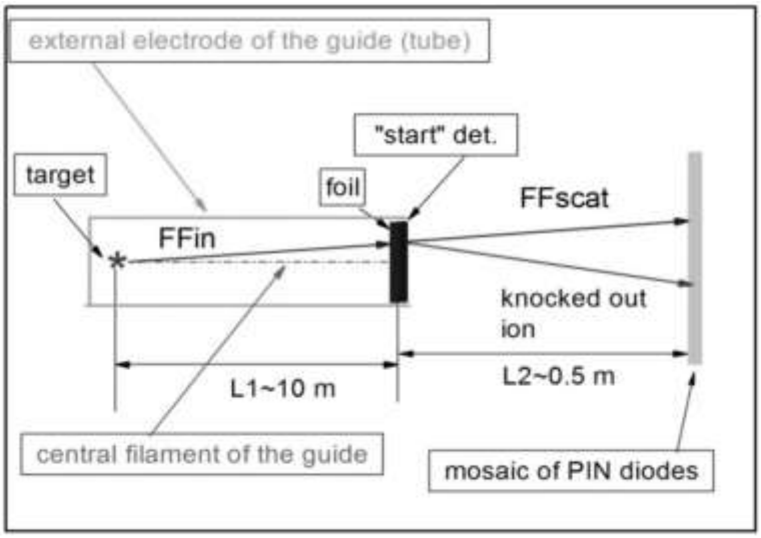

FIGURE 3. Layout of the spectrometer to be used for estimating of the life time of shape-isomers under study.

The second reason for using of a guide based spectrometer in fission studies follows from the fact that the efficiency F_c of the guide is a function of the fragment ionic charge q. It manifests itself in formally absolutely different approach for investigation of fission process namely revealing of so called "fine structures" in the FF M-TKE (mass-total kinetic energy) distributions. As was shown in [9] FF M-TKE distribution is not absolutely smooth but, on the contrary, exhibits local irregularities (peaks). The peaks in the neighboring sections M = const are correlated and constitute regular "snake-like" structures. An example of such structures is shown in fig. 4.

A multi-valley structure of the potential energy surface of a nuclear system – at least, in such reactions as fusion, fission, and quasi-fission – causes the presence of separate ways of evolution of the system, which proceed along corresponding valleys. Each way develops as a trajectory in the space of experimental observables such as mass asymmetry and total kinetic energy. We treat the structures observed as the image of fission modes [10]. It turns out that the snake-like structures correspond to locally higher ionic charge *q* of the fragments [11].

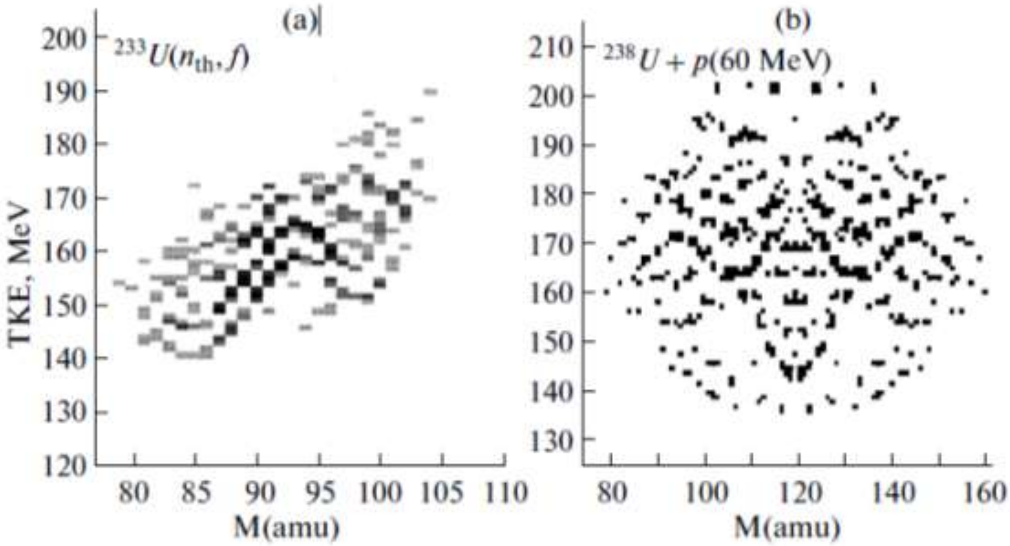

FIGURE 4. Snake-like fine structures found in the mass–total kinetic energy distribution (*M*–TKE) of fission fragments in the reactions (a) ^{233}U(nth, f) and (b) ^{238}U + *p*(60 MeV).

It means additional amplification of these fine structures (better effect/noise ratio) in the M-TKE distributions measured at the guide based spectrometer ***VEGA*** *(Velocity-Energy Guide based Array) to be realized.*

SCIENTIFIC PROGRAM OF THE VEGA PROJECT

Summing up all presented above the following tasks is proposed as a scientific program of the VEGA project.

1. Estimation of the mean life time of the shape isomeric states in fission fragments from the (n_{th}, f) reactions.
2. Direct registration of at least two CCT partners bearing in mind additional angular divergence provided by electrostatic guide for initially collinear fragments [8].

STATUS OF THE VEGA PROJECT

We are going to realize VEGA as a one-armed time-of–flight spectrometer at the vertical experimental channel of the IBR-2 reactor. It means that the basic distribution similar to those shown in Figure 2 cannot be obtained. In other words in this case we have not attributive sign of inelastic process under analysis namely missing mass of the fragments from the initial binary fission. Fortunately, the spectra from a conventional binary fission and those measured in coincidence with the knocked out ion from the degrader foil differ substantially even for one-arm configuration of the spectrometer (Figure 5). The latter summarizes the data obtained at the COMETA setup [3]. Strong peak of ^{128}Sn isotope in between the humps of binary fission can be judged as an indication of inelastic scattering of the fragments in the degrader foil.

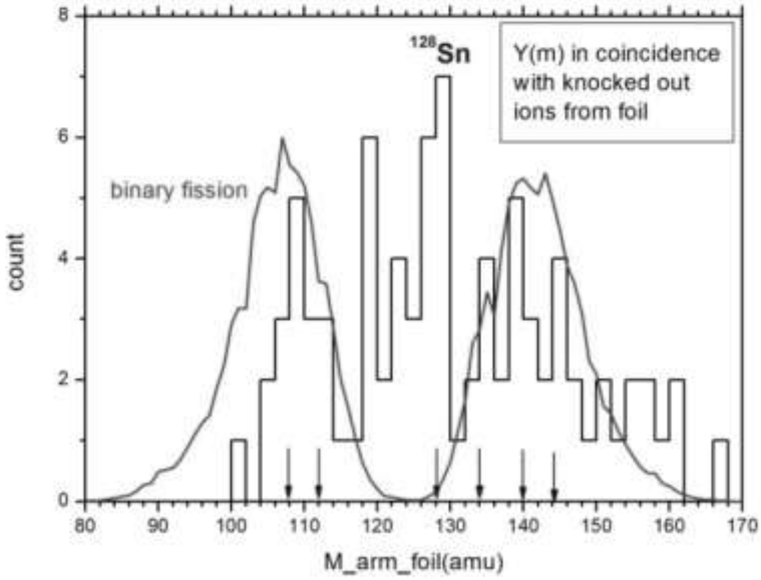

FIGURE 5. Comparison of the mass yields from the conventional binary fission (in red) and those measured in coincidence with the knocked out ion from the degrader foil where brake-up of the fragment in the shape isomeric state appears to occur. The arrows show the masses of known magic nuclei.

At this time technical details of the VEGA project are under consideration. The overall view of the setup is presented in fig. 6. The bottom part of the experimental channel with the guide inside is shown in fig. 7.

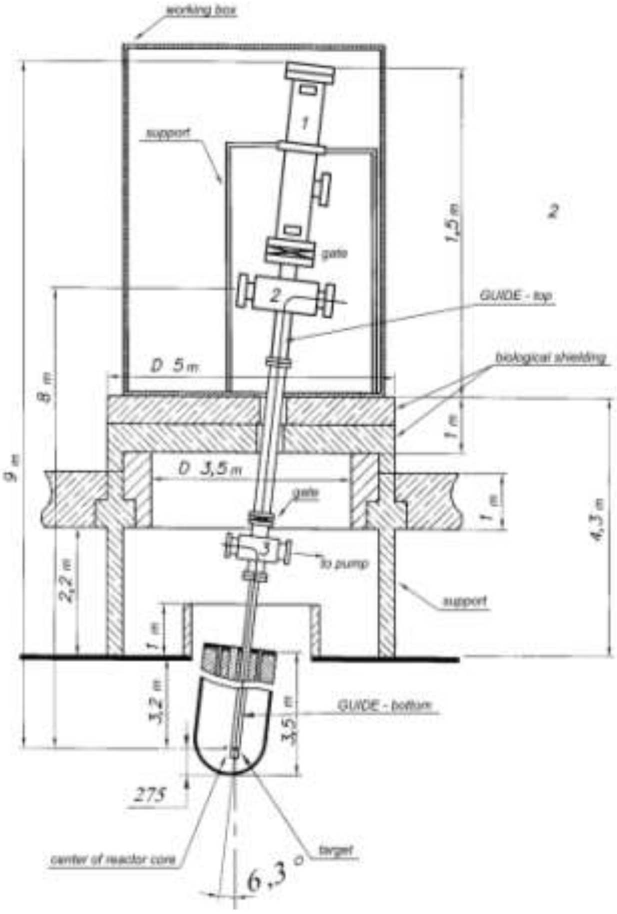

FIGURE 6. Layout of the VEGA setup at the vertical experimental channel of the IBR-2 reactor.

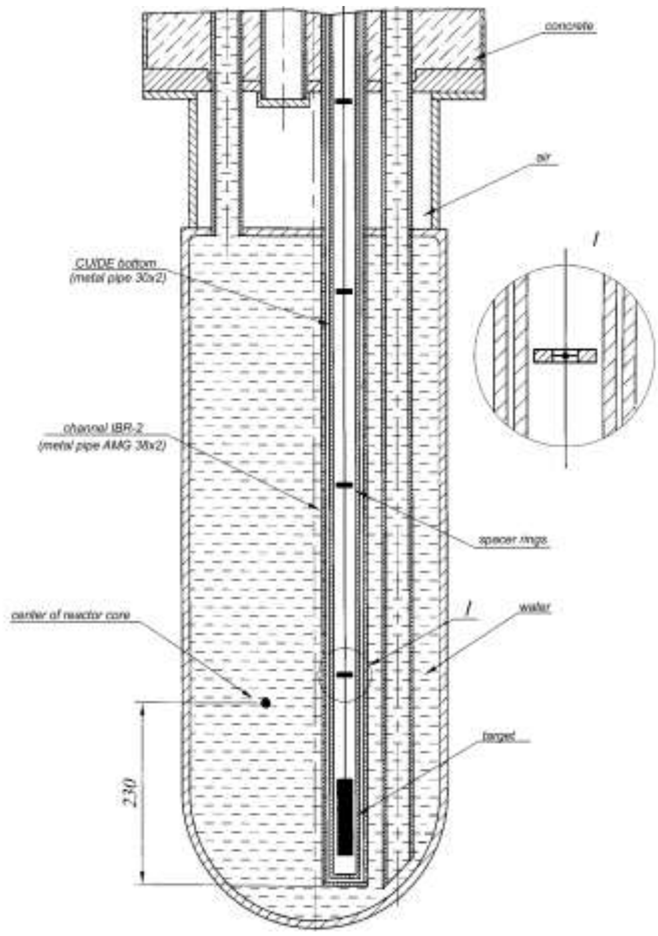

FIGURE 7. Bottom part of the experimental channel with the electrostatic guide inside.

CONCLUSION

Summing up all presented above, the following points should be stressed. Using of the electrostatic based guide system (VEGA setup) for studies of fission process lets to perform the experiments to be hardly possible in the frame of alternative methodics. The first feature of the guide to be mentioned is the almost constant intensity of the beam of ions already captured into the guide along the flight-pass which can be very long (more than ten meters). We are going to exploit this feature for estimating of the life time of shape isomers in flight.

By definition, the collection efficiency F_c of the guide is proportional to the ionic charge of the fragment captured. Due to the link between the excitation energy (Eex) of the nucleus and a coefficient of the internal conversion (at least for the light FFs) which manages the FF ionic charge there is a “bridge” between intimate nuclear parameter (excitation energy of the nucleus) and atomic one namely ionic charge. In its turn, nuclear states with higher Eex are expected to have higher yields. Detecting of the states with locally increased Eex (for instance, on the FFs M-TKE plane) gives unique possibility to visualize the most probable reaction (fission) ways.

ACKNOWLEDGMENTS

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