MEASURING OF THE FRAGMENTS NUCLEAR CHARGES AT THE MINI-FOBOS SPECTROMETER

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Abstract. Method of measuring and calibration of fission fragments nuclear charges is described. The nuclear charge was determined by measuring of the drift time of a track formed after stopping of a fragment in the gas-volume of the high aperture ionization chamber. This method was applied at the MiniFOBOS spectrometer in the experiment aimed at studying of the $^{235}U(n_{th}, f)$ reaction. The experiment was performed at the IBR-2 beam in FLNP of the JINR. The nuclear charge proves to be important additional parameter for reliable identification of the collinear multicluster decay products [1] searched for.

EXPERIMENTAL SETUP

MiniFOBOS setup (fig. 1) is a double armed time-of-flight-energy spectrometer based on the standard detector modules (fig.2) of the 4π- spectrometer FOBOS. Each detector module used consists of position-sensitive avalanche counter (PSAC) and an axial big ionization chamber (BIC) which registered the full energy of the fragments. The drift time of a track formed after stopping of a fragment in the gas-volume of the BIC is known to be linked with the fragment nuclear charge [2]. Corresponding parameter was measured as a time difference between PSAC signal and the signal from the Frisch grid of the BIC.

Specially designed start-detector represents symmetrical avalanche counter (SAC) with an internal target (fig. 3). An active layer of the target was prepared by evaporation of 100 μg/cm² of ^{235}U isotope on Al_2O_3 backing of 50 μg/cm² thick.

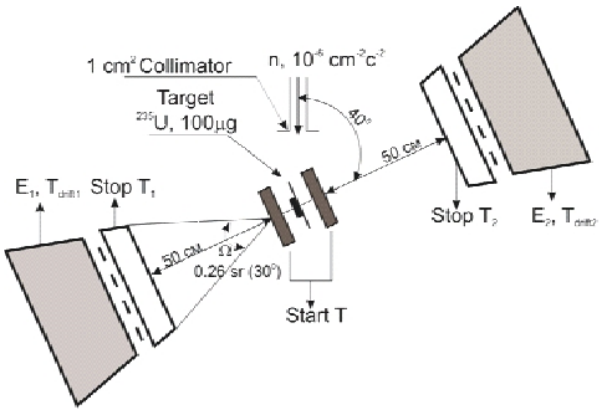

FIGURE 1. Scheme of the experimental setup

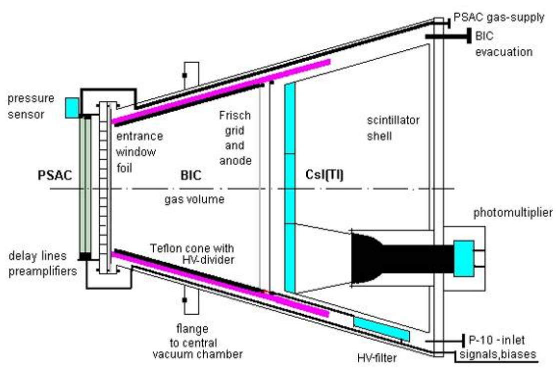

FIGURE 2. Detector module of MiniFOBOS spectrometer

THE NUCLEAR CHARGE CALIBRATION PROCEDURE DEVELOPED

The parameterization of a fragment range in a gas volume was successfully applied in Ref. [3].

The range of a particle can be expressed as

$$R = L - D \cdot V_{drift}, \quad (1)$$

where L – is the distance between entrance window and Frisch grid, D – drift time of a track, V_{drift} – drift velocity of electrons forming the track.

The Bohr-Wheeler [4] relation was applied for description of a particle range:

$$R = \beta \sqrt{EM}\, Z^{-2/3}, \quad (2)$$

where E – is the energy of fission fragment (FF), M – FF mass, Z – FF nuclear charge.

Fragment momentum can be expressed as:

$$P_{BIC} = \sqrt{1.923EM}. \quad (3)$$

Using expressions (1-3) one can obtain:

$$D = \alpha - \beta \cdot P_{BIC} \cdot Z^{-2/3} + \gamma M + \delta E, \quad (4)$$

where α, β, γ, δ are the parameters to be calculated .

Thus one need a parameter vector Y(α,β,γ,δ) for calculating the FF Z-value basing on formula (4):

$$Z = \left(\frac{\beta \cdot P_{BIC}}{\alpha - D\_\exp + \delta E} \right)^{3/2}. \quad (5)$$

An algorithm for calculation of vector Y (Z – calibration procedure) starts from generation of matrix "Drift time – energy in BIC" (fig.3) using experimental data for the fixed Mtt value (FF mass obtained in the frame of the velocity-velocity method).

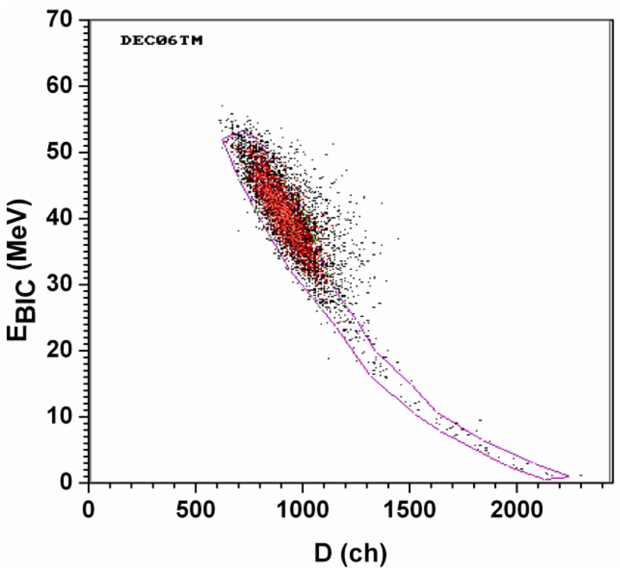

FIGURE 3. "Drift time vs. energy in BIC" dependence for the FF having fixed Mtt mass = (97±1) a.m.u.

A "tail" of the main locus in the figure is due to the FF scattered on the supporting grid of the BIC. Selected Mtt value is corrected in order to take into account emitted neutrons (fig. 4), in other words, mean post-neutron mass value is obtained which is used for calculation of the FF momentum P_{BIC} in the BIC.

At the next step one obtains the (<D_exp> vs.P_{BIC}) dependence by means of averaging of D_exp values at each momentum value. Simultaneously Z- value is calculated for each event involved in the distribution in fig. 3 using current parameters vector Y. This vector is changed in the frame of the procedure based on the MINUIT minimization code [6] in order to minimize purpose function which represents the quadratic difference between both experimental and calculated curves D(P_{BIC}) and <Z> for Mtt mass selected for calibration. Reference Z values are calculated according Z_{ucd}-hypothesis within the corrections from [7] (fig. 5).

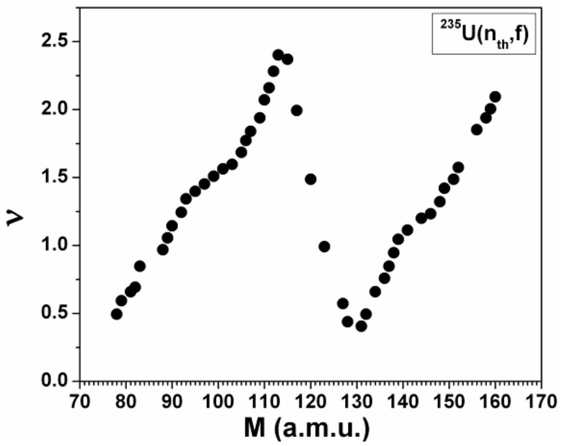

FIGURE 4. Average number of neutrons vs. pre-neutron mass for the reaction $^{235}U(n_{th},f)$ [5].

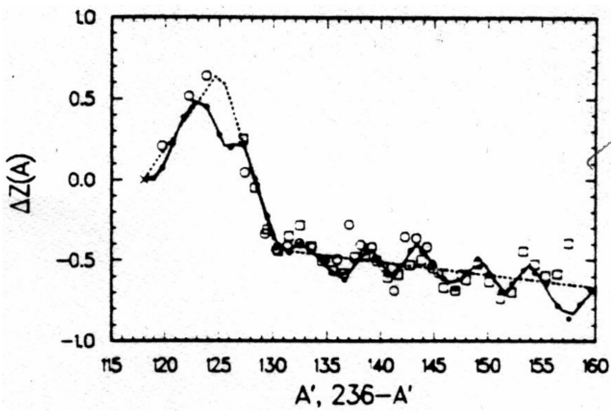

FIGURE 5. Corrections to the FF Z-value calculated according Z_{ucd} hypothesis [7].

The scheme of the Z-calibration code is presented below (fig. 6).

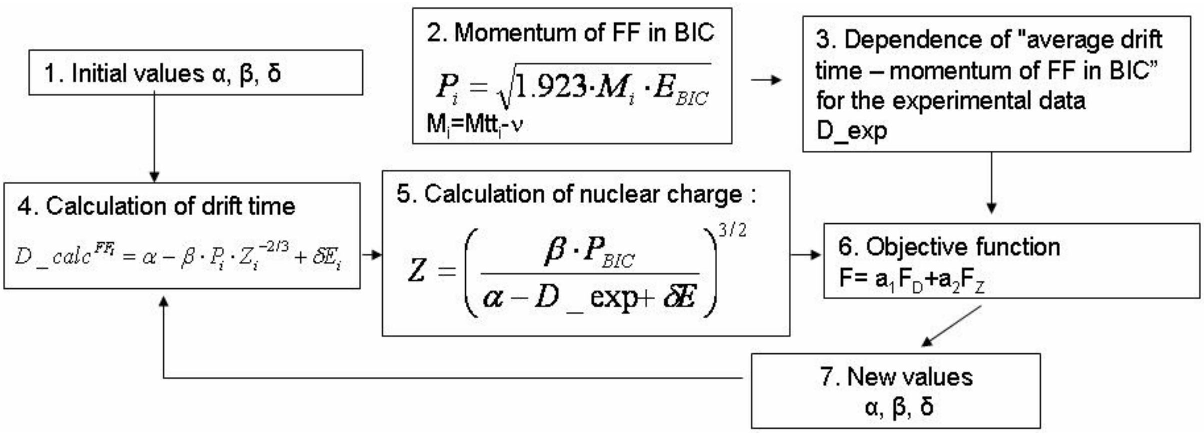

FIGURE 6. Scheme of the Z-calibration code developed.

TESTING OF THE CALIBRATION PROCEDURE

In order to test the calibration procedure developed simulations based on the quasi-experimental data were performed. The following parameters similar to the experimental ones were used for generation of the model data:

-the BIC is filled by Ar at a pressure of 11 kPa;

-the distance between entrance window and Frisch grid is equal to 26 cm;

-the temperature is 19^{o}C;

-the density of the gas is equal to $1.85*10^{-4}$ g/cm^3.

The range of the particles was calculated using computer code SRIMM 2006 [8] with PRAL algorithm (Projected Range Algorithm, J.P. Biersack [9]).

Table 1. The charges and energies of the fragments tested.

Z	6	8	10	15	20	23	32	34	37	51	55
E, MeV	1-15	1-30	1-30	1-30	1-30	1-40	1-50	1-60	1-45	1-25	1-20

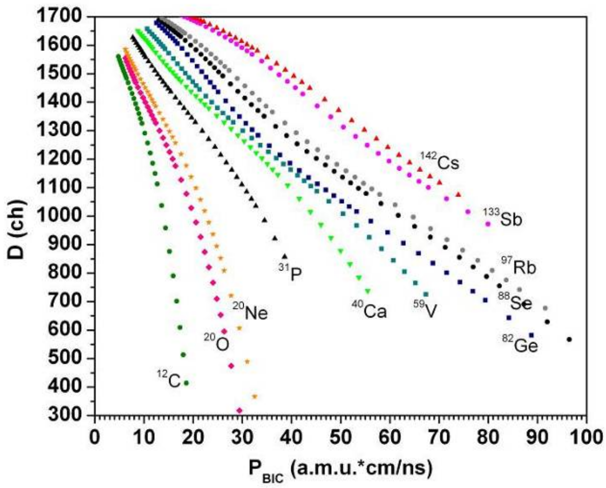

FIGURE 7. "Drift time vs. momentum of the FF in the BIC" model dependences obtained by the SRIMM code.

As can be referred from the figure the curves D(P) have rather complicated shape varying smoothly while nuclear charge is changed. Comparison of the calculated D(P) dependences with model and experimental are shown in fig.8a and fig.8b respectively. From the figures we observe that calibration proposed gives quite satisfactory description of both model end experimental data for typical fission fragments of the light mass peak in wide energy range.

An agreement of the calculated D(P) dependences with the data for heavy fragments is much worse (fig. 9), especially for the model data. Likely it shows on miscalculations of the heavy ions ranges by SRIM code in this region.

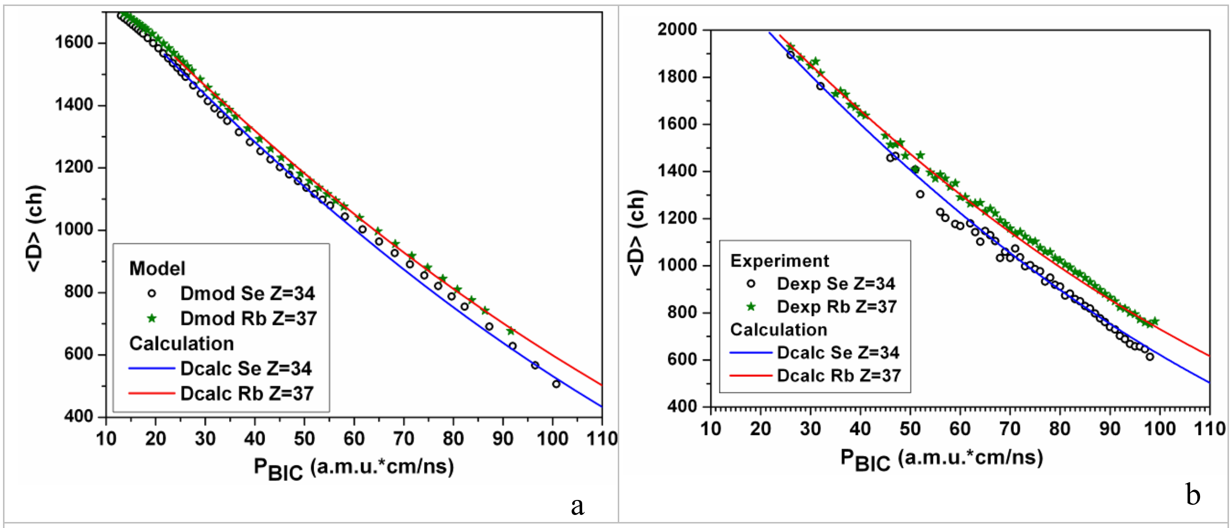

FIGURE 8. Comparison of the calculation with the modeling (a) and the experimental (b) data for FFs with masses 88 and 97 a.m.u.

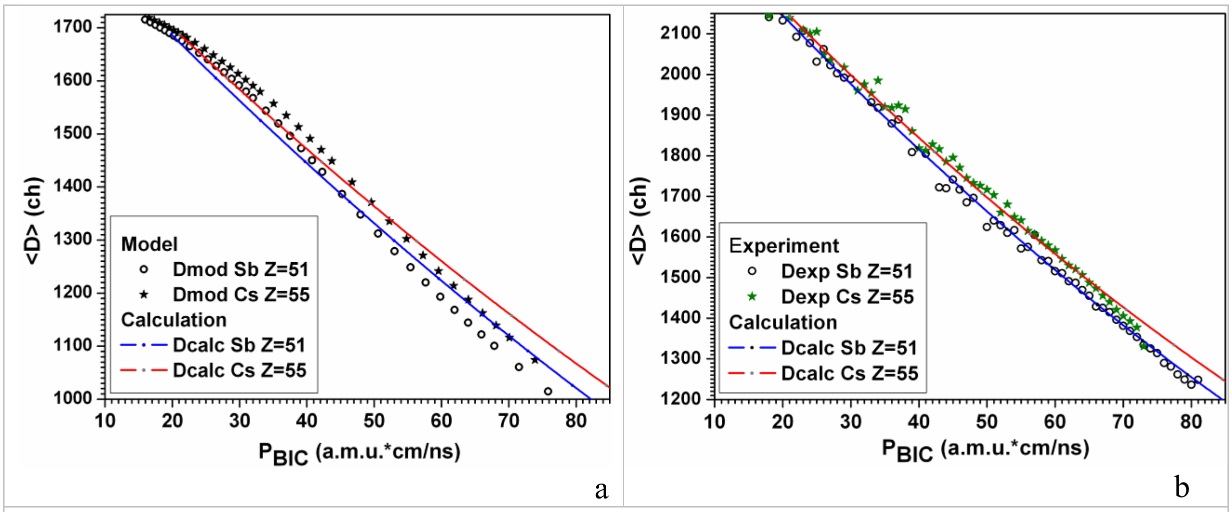

FIGURE 9. Comparison of the calculation with the modeling (a) and the experimental (b) data for FFs with masses 133 and 142 a.m.u.

LIMIT OF LIGHT IONS

In our previous experiments devoted to searching for collinear multicluster decays we observed fragments of different masses including light ions. It was interesting whether parameterization (4) is suitable for estimation nuclear charges of light ions as well. Corresponding results are shown in figs. 10, 11. One can refer from the figures that the calculated curves are shifted reference to model (quasi-experimental) ones approximately on two charge units.

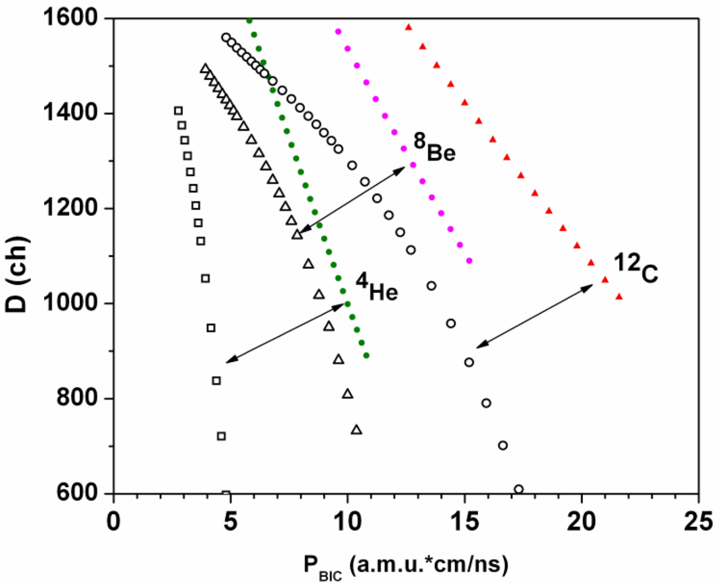

FIGURE 10. Comparison of simulated data (empty symbols) with calculations based on expression (4) for ^{4}He, ^{8}Be, ^{12}C ions.

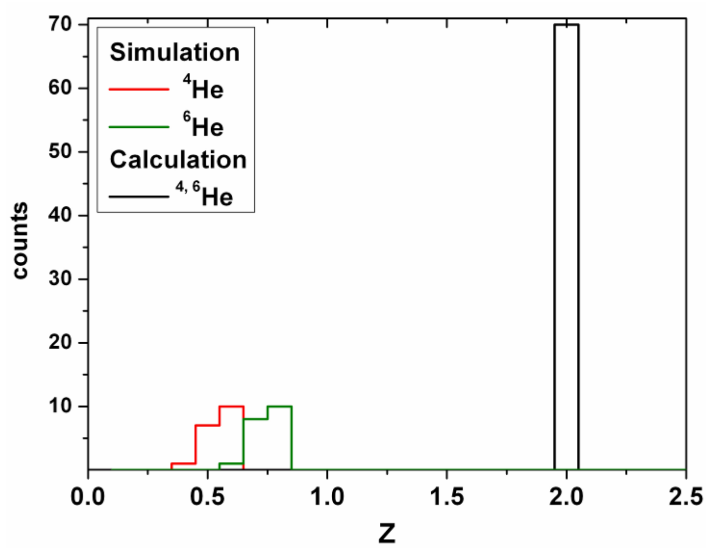

FIGURE 11. Comparison of simulated data with the results of calculation based on expression (4) for ^{4,6}He ions.

Table 2. Parameters of the nuclear charge spectrum of the FFs from the reaction ^{235}U(n_{th}, f).

	MiniFOBOS		Lang et al [10]
	Modul 1	Modul 2	
<Z>, light FF peak	38.18	38.22	37.92
FWHM	6.45	7.06	5.43
<Z>, heavy FF peak	52.26	53.02	53.92
FWHM	10.43	10.71	5.43

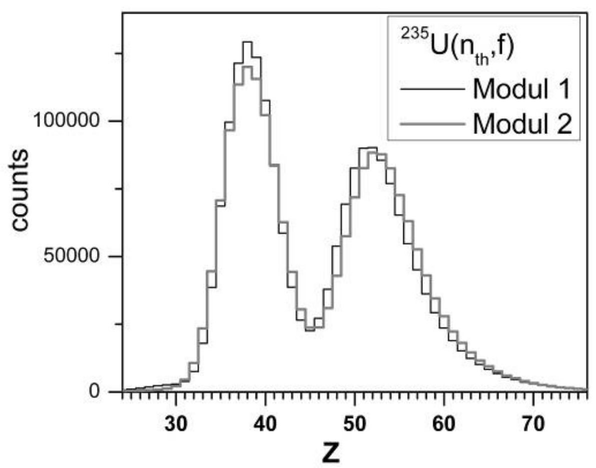

FIGURE 12. Nuclear charge spectrum of the FF from the reaction $^{235}U(n_{th}, f)$ (shown separately for each spectrometer arm)

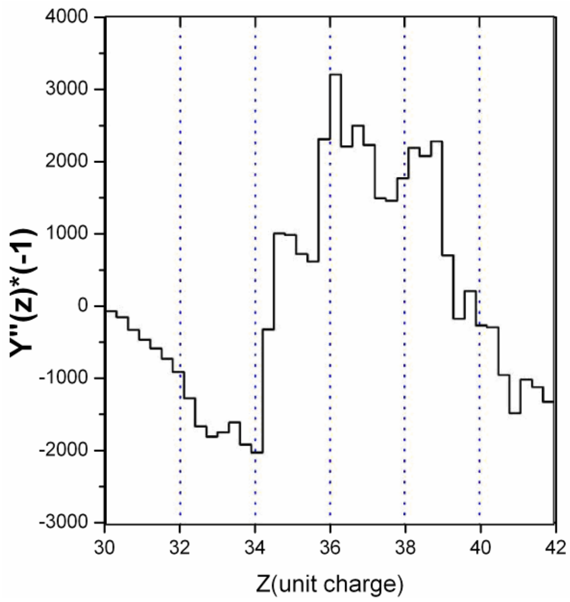

FIGURE 13. Second derivative of nuclear charge spectrum multiplied by factor (-1).

CONCLUSION

Measuring of the fission fragments nuclear charges proves to be more complicated experimental problem in comparison with measuring of energy. Charge resolution depends crucially from both electric field uniformity and permanency of the mass of the gas in the volume of the ionization chamber. Necessary conditions were provided in our experiments at the miniFOBOS spectrometer. Special calibration procedure was developed for calculation of the FF nuclear charge which depends from the parameters measured in the experiment. Simulation showed that the approach developed satisfactory works in a wide range of the FF's energies but gives a little bit shifted values for very light ions.

ACKNOWLEDGMENTS

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