Письма в ЭЧАЯ. 2016. Т. 13, № 5(203). С. 898–904

МЕТОДИКА ФИЗИЧЕСКОГО ЭКСПЕРИМЕНТА

NEW TRENDS IN THE DEVELOPMENT OF “ACTIVE CORRELATIONS” TECHNIQUE

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With reaching extremely high intensities of heavy-ion beams, new requirements for the detection system of the Dubna Gas-Filled Recoil Separator (DGFRS) will definitely be set. One of the challenges is how to apply the “active correlations” method [1–6] to suppress beam associated background products without significant losses in the whole long-term experiment efficiency value. Different scenarios and equations for the development of a method according to this requirement are under consideration in the present paper.

PACS: 07.05.Wr

INTRODUCTION

Significant success has recently been achieved in the field of SHE synthesis and studies of radioactive properties of superheavy nuclei. With the discovery of the “island of stability” in experiments with ^{48}Ca projectiles at the Dubna Gas-Filled Recoil Separator (DGFRS), one can raise a question about sources and components of such a great event. Intense heavy-ion beams and exotic actinide target materials were certainly strongly required in experiments. However, final products of the DGFRS experiments were rare sequences of decaying nuclei signals. In this connection, the role of the DGFRS detection system was crucial. Specifics of the DGFRS detection system is application of the “active correlations” method. Using this technique, it has become possible to provide deep suppression of background products with negligible losses in the value of the whole experimental efficiency. Moreover, experiments at the DGFRS, when the above-mentioned method was not applied, yielded ambiguous results [6]. To briefly clarify method application, a process block diagram is shown in Fig. 1, *a*. A short beam stop was generated by the ER-α sequence detected in real-time mode. Extra time which is required for one cycle searching is shown in Fig. 1, *b* (i3-2100 CPU@3.10 GHz).

Note that in most of the DGFRS experiments, one of the two first alpha-particle signals was used as a trigger signal for a break point in target irradiation.

It is evident that application of the “active correlations” method will cause more than usual break points in continuous, long-term actinide target irradiation and, therefore, will result in additional losses in experimental efficiency. With no further modification of the method,

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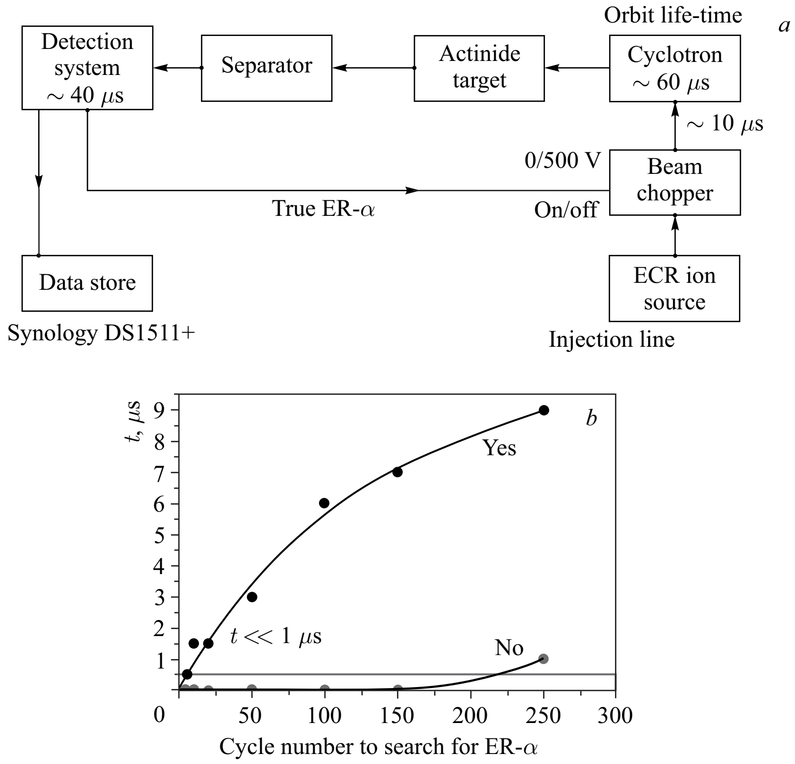


Fig. 1. *a*) Block diagram of real-time process. Two key elements are shown in yellow. *b*) Extra time $t \ll 1$ μs which is required ($n = 1$ is actual) to search for ER-α correlation (Yes scenario)

the loss value may reach tens of percent ($\sim 5-10$ pμA intensity), which does not definitely contribute to success in challenging experiments that require a lot of resources. One should note that there are other problems related to high-beam intensities, except for detecting. For instance, the development of the rotating actinide target is one of them. Additionally, this paper completes a series of works aimed to solve issues related to the DGFRS long-term experiment automation.

DSSSD DETECTOR APPLICATION IN ^{240}PU + ^{48}CA REACTION EXPERIMENT

The experiment was performed at the DGFRS using ^{48}Ca beam accelerated at the U400 cyclotron of the FLNR, JINR. The ^{48}Ca ion beam was delivered to the target with a maximum intensity of 1.3 pμA. The beam energy was determined with a systematic uncertainty of 1 MeV by a time-of-flight system placed in front of the DGFRS. The target materials were provided by the Oak Ridge National Laboratory (ORNL) (98.97% enrichment). Evaporation residues (ERs) recoiling from the target were separated in flight from ^{48}Ca beam ions, scattered particles, and transfer reaction products by the DGFRS. Recoils passed through a time-of-flight (TOF) system consisting of two multi-wire proportional counters (MWPCs) placed in pentane at a pressure of about 1.5 Torr. A 0.2-mg/cm^2 Mylar foil separates the detection system from the DGFRS volume which is filled with hydrogen at a pressure of 1 Torr. The array of silicon detectors at the DGFRS final focus was modified to increase the position resolution of recorded signals and subsequently reduce the probability of observing sequences of random events that mimic decay chains of implanted nuclei. The new detection system includes a 0.3-mm-thick double-sided silicon strip detector (DSSSD) manufactured by Micron-Semiconductor, Ltd. (model BB-17). This large DSSSD has 1-mm-wide strips, 48 on the front side and 128 on the back side, thus creating 6144 1-mm^2 pixels in one silicon wafer (Fig. 2, *a*, *b*).

Such high pixilation helps to achieve superior position resolution for recoil-alpha correlated decay sequences reducing potential random events. The detection efficiency of the

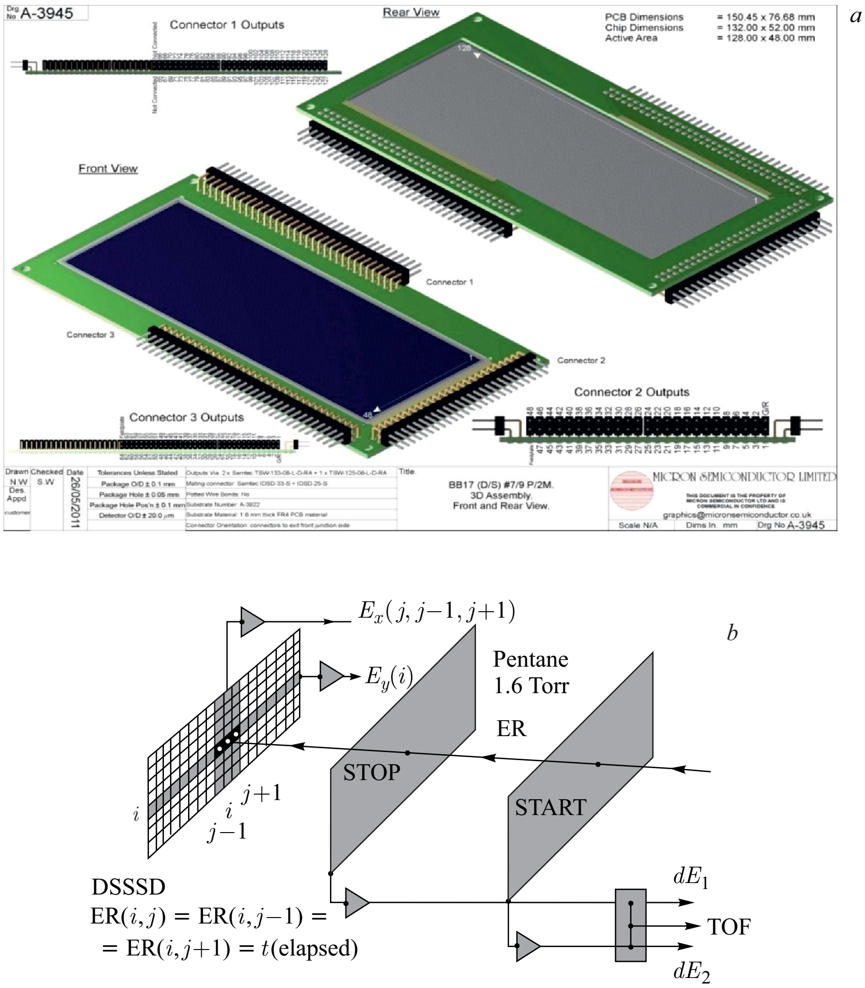


Fig. 2. DSSSD detector of the DGFRS (*a*) and schematics of "beam off" intervals creating (*b*). The formation process for ER matrix is shown in (*b*). Edge effects for neighbor back-side strips are taken into account (for some cases one may apply two neighbor pixels of ER's matrix except for three ones)

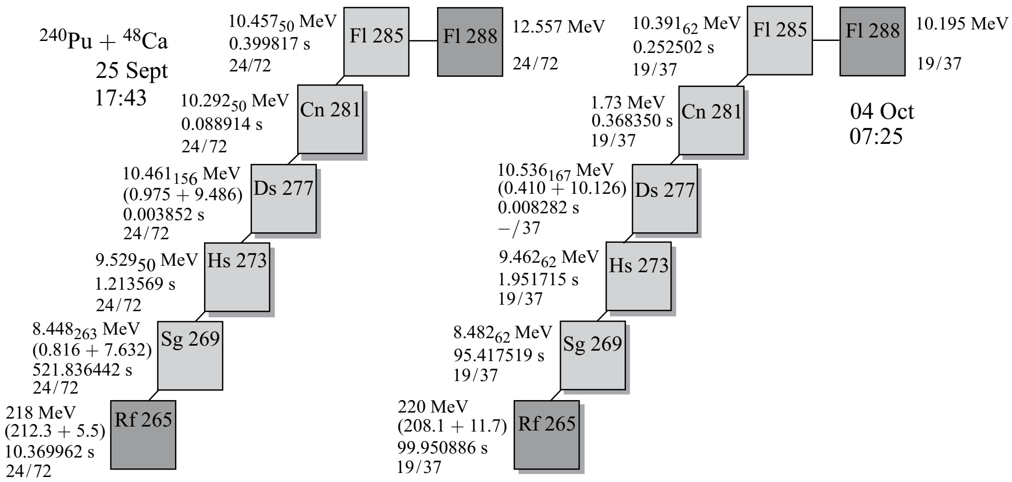


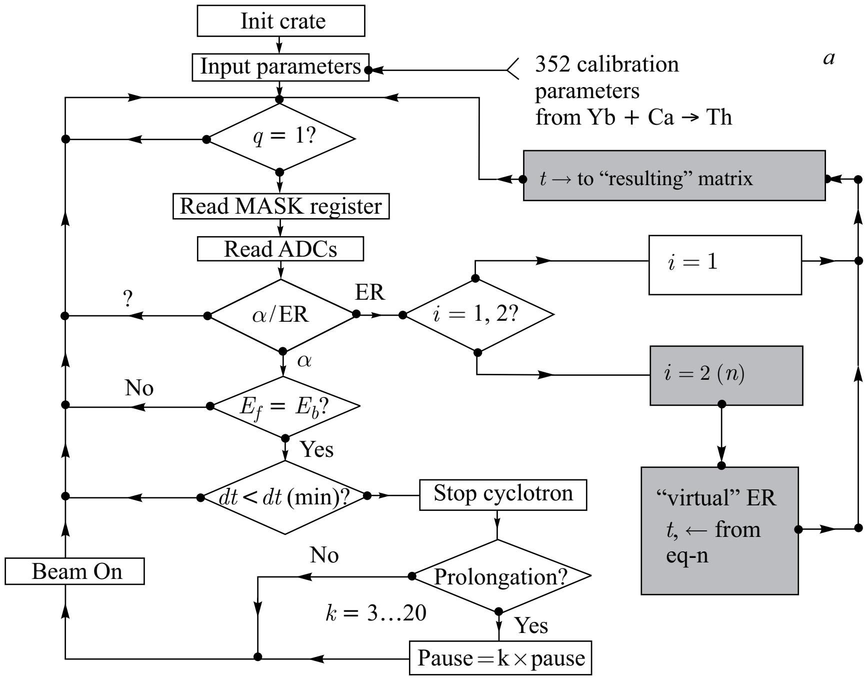
Fig. 3. Two registered sequences of $Z = 114$ nuclei. (Shadows are beam off phases. See also [6])

implantation DSSSD is about 52% for α particles with ≈ 10 MeV emitted from the implanted nuclei. This detection scheme allows beam interruption which occurs after the detection of recoil signals with the expected implantation energy for $Z = 114$ evaporation residues followed by an α-like signal in the implantation detector with the energy of 9.8–11.5 MeV, both in the front and back strips, i.e., in the same 1-mm^2 DSSSD pixel. The ER energy interval was chosen to be 6–16 MeV. In Fig. 3, two sequences of $Z = 114$ nuclei are shown.

An "Indefinite Start" Problem in Searching for ER-α Sequence Real-Time Mode. In [7], an exhaustive approach to the above-mentioned problem is presented, whereas in [4], an express one is reported. An effective registered life-time was defined in [4] as $\tau_{\rm eff} = \sum_{i=1}^{n} w_i t_i / w_i$, where t_i is measured time for ERi-α sequence and w_i is its statistical weight value [3, 4]. It was shown that an additional dead-time value to solve the equation in an attempt to find the effective life-time value was about 1–3 μs, if one applies an ordinary iteration or the Newton method. The flowchart of the data taking process is shown in Fig. 4, *a*. Subroutines to obtain an effective life-time value are marked in grey. Figure 4, *b* demonstrates the convergence process rate for the Newton iteration method. The appropriate weight function is $w_i(\tau, t_i) = \exp\left(-\dfrac{t_i}{\tau}\right)\left[1 - \exp\left(-\dfrac{t_i}{\tau}\right)\right]$.

Note that if one uses the $\tau_0 = \sqrt[2]{t_1 t_2}$ value to a first approximation, an accuracy of about a few percent can sometimes be achieved in the next iteration step. The presented weight function can certainly be added by factors, which are taken into account when measuring recoil's registered energy, ΔE signal shape and background signals frequency (average time between two recoil signals per pixel). That is

$$w_i(\tau, t_i) = F(E_i^{\rm reg}) F(\Delta E_i^{1,2}) \exp\left(-\frac{t_i}{\tau}\right)\left[1 - \exp\left(-\frac{t_i}{\tau}\right)\right] \frac{1}{1 - \exp\left(-\dfrac{t_i}{\tau_{\rm ER}}\right)}.$$



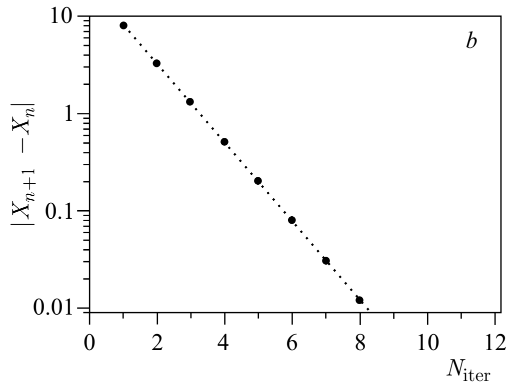


Fig. 4. *a*) The flowchart of ER-α search process ($k = 3-20$). *b*) The convergence process for the Newton iteration method. (Y axis is displayed as %, X axis represents number of iterations)

In this formula, $\tau_{\rm ER}$ is the average value of time interval between two ER signals per pixel (Poisson statistics).

For recoil mean registered energy, one may apply the following formula [8]:

$$\langle E^{\rm reg} \rangle \approx -2.05 + 0.73 E_{\rm in} + 0.0015 E_{\rm in}^2 - \left(\frac{E_{\rm in}}{40}\right)^3, \quad 5 < E_{\rm in} < 45 \text{ MeV},$$

where $E_{\rm in}$ is the incoming ER energy signal value. Typical ΔE spectra are shown in Fig. 5.

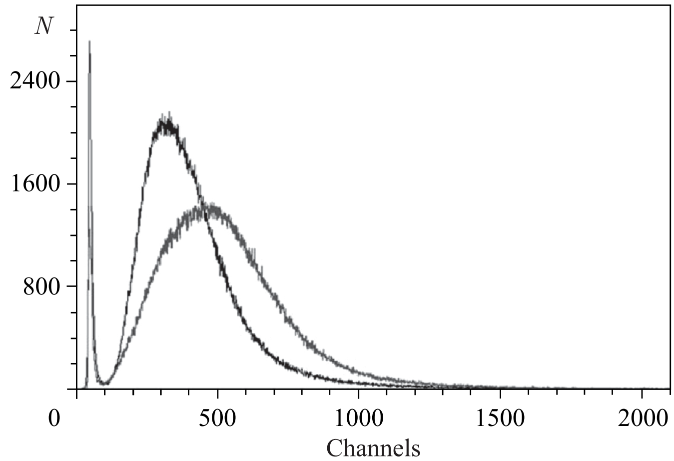


Fig. 5. ΔE spectra (channels) measured with the START and STOP low-pressure proportional counters of the DGFRS

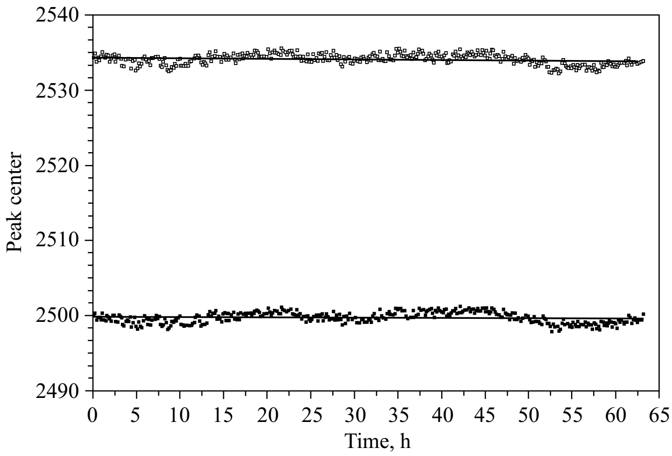


Fig. 6. Tests for the ADP-16 TechInvest module (bottom graph is a 65-h stability test)

ADP-16 TechInvest as a Basic Unit for Upcoming Spectrometer. Sixteen inputs (two scales) 1M CAMAC experimental module by TechInvest (Dubna Special Economic Zone) was tested as a base unit for the DGFRS spectrometer which is to be manufactured in the near future. In fact, this integral module incorporates the functions of a shape amplifier, analog multiplexer, and analog-to-digital converter. The results of the 65-h thermo-stability test are shown in Fig. 6. Note that an alternative spectrometer design is reported in [9].

SUMMARY

The DSSSD based detection system of the DGFRS was for the first time successfully applied in the $^{240}\mathrm{Pu} + {}^{48}\mathrm{Ca} \rightarrow {}^{*}\mathrm{Fl}$ heavy-ion-induced complete fusion reaction using the "active correlations" method. The prototype of the Builder C++ data taking code was designed and successfully tested.

The author does not preclude application of correlation sequence signals, like ER & α_1 & α_2, to provide a deeper suppression of beam associated backgrounds, except for a more traditional ER & (α_1 OR α_2) though the DSSSD threshold lower than ~ 200 keV is strongly required in this case. A possibility of enabling the operational mode — when a single ER signal creates a short-beam off-time interval in parallel with the main algorithm execution — is also under consideration.

Acknowledgements. The author would like to thank Dr. A. N. Polyakov and Dr. A. N. Kuznetsov for their invaluable help in testing of the ADP-16 TechInvest module.

This paper is supported in part by the RFBR, grant No. 16-52-55002.

APPENDIX

When preparing this manuscript good news was coming from IUPAC. Namely:

"The collaboration between the Joint Institute for Nuclear Research in Dubna, Russia; Lawrence Livermore National Laboratory, California, USA; and Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA, have fulfilled the criteria for elements $Z = 115,\ 117$ and will be invited to propose permanent names and symbols" [10].

Note that the method of "active correlations" was playing a significant role during those experiments.

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