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NEW ANALOG SPECTROMETER OF THE DGFRS2 SETUP FOR REAL-TIME SEARCHING OF ER-α AND α–α CORRELATED SEQUENCES IN HEAVY-ION INDUCED COMPLETE FUSION NUCLEAR REACTIONS*

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A new analog spectrometer of the DGFRS2 setup installed at new FLNR DC-280 ultra-intense cyclotron has been designed. The main goal of application of this spectrometer is to provide deep backgrounds suppression in different heavy-ion induced nuclear reactions using real-time detection mode of short correlated sequences such as ER-α, α–α or even ER-α–α. Integral 1M CAMAC analog-to-digital processor ExTech ADP-16 is used as a basic unit in the spectrometer design. A new real-time flexible algorithm is presented in addition to the conventional ER-α one which is in use for a few years at the DGFRS1 setup installed at the U-400 FLNR cyclotron. Note that the spectrometer operates together with the 48×128 strip DSSD (Double Side Strip Detector) detector and low pressure pentane-filled gaseous detector. To perform the real-time operation mode, we define an abstract mathematical object like "correlation graph" containing $n(n-1)/2$ links. An experimentalist can use each link as trigger signal for beam stop. Here n is the number of nodes for this graph. First tests of the spectrometer at intense beam of ^{48}Ca projectile are presented too.

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1. Introduction

One of the fundamental outcomes of the nuclear shell model is a prediction of the existence of the "Island of Stability" in the domain of the hypothetical superheavy elements. This hypothesis has been under development for more than 50 years in various nuclear models, and again finds support in the most recent experiments on the synthesis of superheavy elements. The Dubna Gas-filled Recoil Separator, operated at the U400 cyclotron at the Flerov Laboratory of Nuclear Reactions, is one of the most efficient existing separator systems used to separate heavy products of the complete fusion nuclear reactions. Namely, with this setup, new SHE with $Z = 114$–118 (Fl, Mc, Lv, Ts, Og) were discovered at the beginning of the millennium [1–4]. Since the cross sections of superheavy nuclei formation in heavy-ion induced complete fusion nuclear reactions are small enough, the main requirements for the experiments aimed at the synthesis of SHE are:

— intensity of HI projectiles should be high enough;

— design of the rotating target should be perfect to provide long term non-destructive application;

— separating factor of the gas-filled separator should be high enough to suppress the background products;

— the detection system should be sensitive enough to have the possibility to extract very rare alpha-decay chains.

The present paper is aimed at the last indicated item taking into account very high intensities of heavy-ion beams from the DC-280 FLNR (JINR) cyclotron.

2. Detecting module and measurement system

The separated EVRs passed through a ΔE measurement system composed of a multiwire proportional chamber [5–7] placed in pentane at a pressure of 1.200 ± 0.0017 Torr and were finally implanted in the detector module installed in the focal plane of the separator. The ΔE information is used to discriminate the particle that passed through the separator from α-particles or spontaneous fission (SF) of implanted EVRs. The ΔE chamber is mounted 65 mm from another plane with -200 V potential in order to eliminate the influence of space charge in the vicinity. A sensitive area of this chamber is about 230×80 mm^2. The focal plane DSSD detector has twelve 48×128 strips (1×2 mm^2 "pixels"; horizontal, vertical) [8]. The detector is used to measure energies of EVRs, sequential α-decays and spontaneous

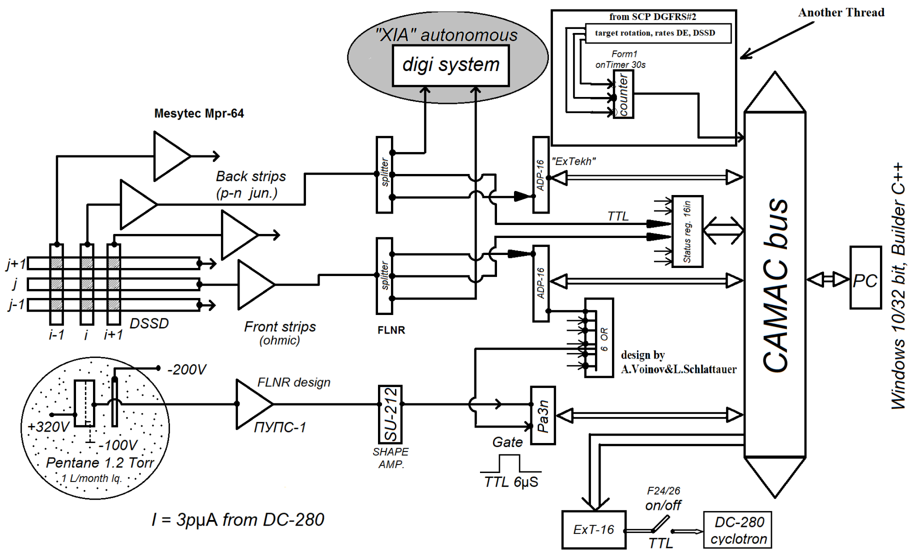

Fig. 1. Block-diagram of the detection system (one electronic channel).

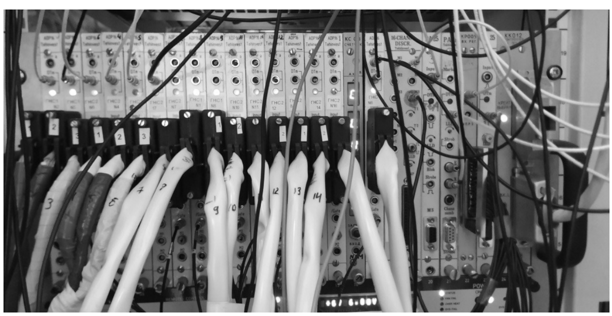

Fig. 2. View of crate with ADP's , Pa3n and Status Register 1M units. 2M "ExTekh16" unit and cable with LEMO connector for TTL signal to stop cyclotron using CAMAC function $N^{*}A(0)^{*}F24$ is shown by marker ring.

fission events. This detector is surrounded by side detectors without position sensitivity. Thus, detection efficiency for α-decay of implanted nuclei is increased up to about 95%. A set of similar 16 strip Si detectors was mounted behind the detector array and operated in "veto" mode in order to eliminate signals from low-ionizing light particles, which could pass through the focal plane detector ($\sim 330\ \mu$m) without being detected in the ΔE system. In Figs. 1–3 block-diagram for one electronics channel, CAMAC crate with ADP-16 units, and view of mechanical housing of DSSD detector are shown. Data taking process is triggered with a non-zero bit in the status

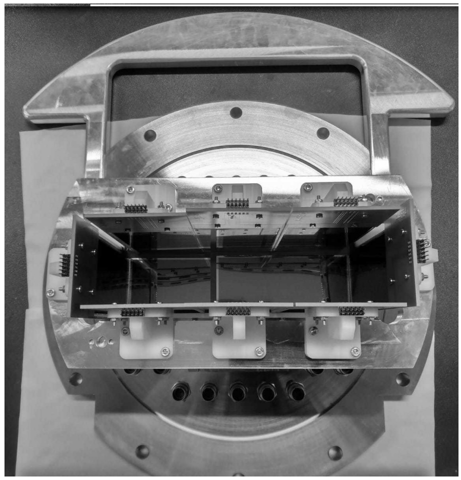

Fig. 3. View of mechanical housing of DSSD detector.

register 1M unit which corresponds to any ADP-16 "L" TTL signal for seven modules. Three of them correspond to 48 strips of DSSD detector, whereas the other seven — to 64 side detectors. Gating Pa3n unit for reading ΔE signals is performed only when a fast signal from any ADP for DSSD detector exists. The duration of "GATE" signal is equal to 6 μs. The detection system has 2.8 μs dead time due to 8 cells ADPs FIFO, whereas regular dead time is about $\sim$ 25 μs. The typical resolution of vertical strips for α-particle signal is about 35 Kev (FWHM). The initial thresholds values (in channels) are written from pre-setting text file and setting procedure is performed using CAMAC function $N^*A(3)F(16)$ for ADPs of DSSD horizontal strips, whereas for vertical strip ADPs, these values are $\sim$ 20% greater than ones written from the file by default. No separate timing modules are used, all times with second and microsecond accuracy were obtained from the Windows 10 system.

3. Tests at the DC-280 ^{48}Ca intense beam

The described above detection system has been tested at the DC-280 ^{48}Ca beam in different nuclear reactions. In our experiments, we apply a specific acquisition mode. Namely, when energy–time–position correlation like ER-α is detected, the system switches the beam off for a short time. Therefore, the forthcoming decay signals are detected in a background-free mode. This method named as "active correlations method" has been described in Refs. [6, 9]. Of course, edge effects between neighbor strips of the p–n junction side were taken into account. The novel feature of the present system in comparison with [5] is a change of initial conditions during the program execution [11, 12]. For example, if we start C++ program acquisition with initial conditions as:

— τ_0 is a first approximation correlation ER-α time value;

— Δt — beam stop pause time *(fixed)*;

— N_{b0} — random correlation expectation for one day acceptable by the experimentalists.

After booting, the new file system estimates every ten minutes an actual expectation value with the extrapolation to 24 hours using mean ER and α-signals rate value, and corrects τ_i parameter. When τ_k corresponds to the condition $|N_b - N_{b0}| < \varepsilon$, where ε is a small positive value, the system stops the iteration process. In Fig. 4, an example of the mentioned algorithm application is shown for ^{243}Am+^{48}Ca $\rightarrow$ Mc* complete fusion reaction. To a first approximation, the τ_0 value was equal to 1 s and $N_{b0} = 3$.

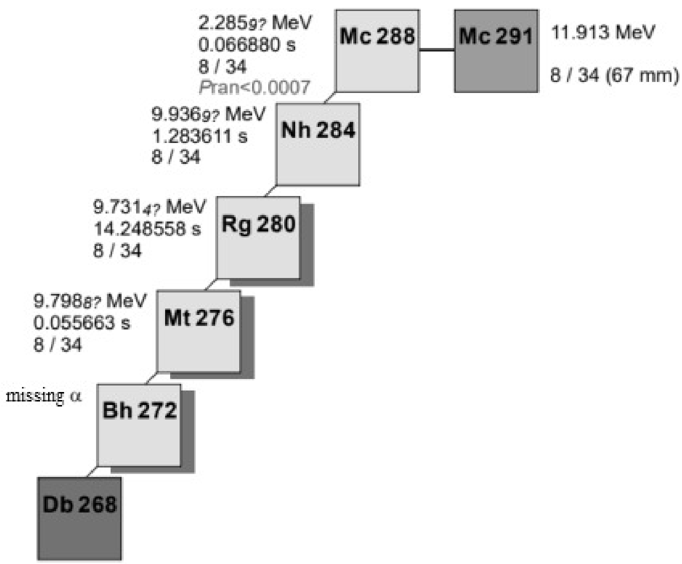

Fig. 4. Decay chain of ^{291}Mc nucleus implanted into DSSD detector. Shadows — signal is within beam off time interval.

In the next ^{242}Pu+^{48}Ca$\rightarrow$^{287,286}Fl+$3,4n$ experiment, 100 decay chains of Fl isotope nuclei were detected. In Fig. 5, spectra of registered energy of implanted flerovium nuclei are shown. Good correspondence to the calculation of Ref. [10] is evident. In Fig. 6, ΔE spectra of both Fl nuclei and background nuclei are shown. Some separation factor values for both spectra

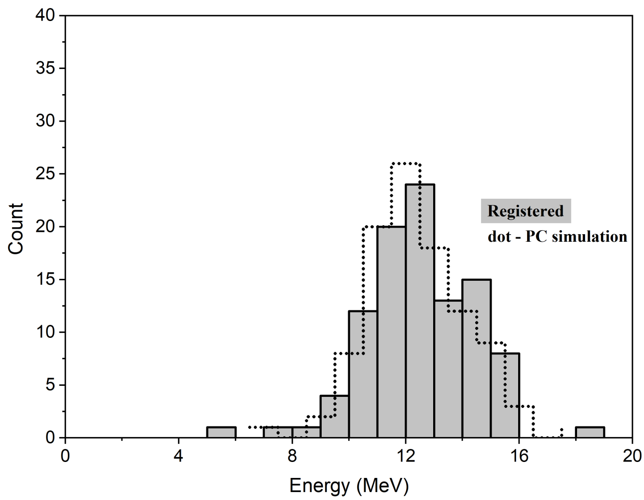

Fig. 5. Registered with DSSD detector and calculated (dotted line) spectra (fragment) of Fl recoil.

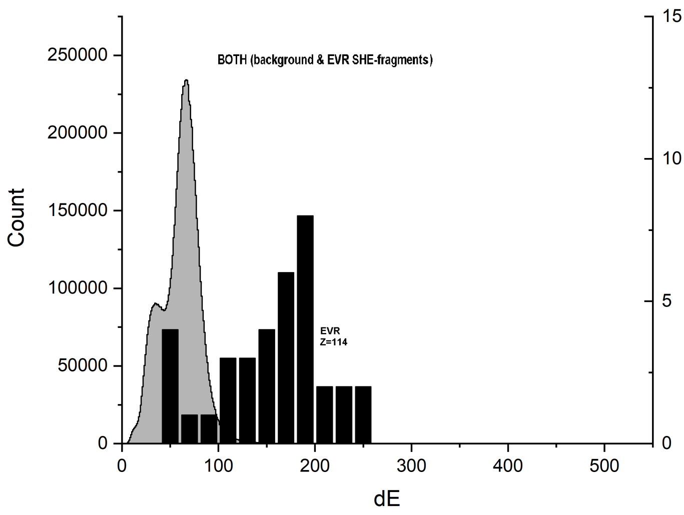

Fig. 6. Spectra Fl recoils (in black) and background nuclei (gray).

(Fl and background nuclei) are evident too. Additionally, one short-time test was performed with a flexible algorithm for ER-α correlation chains search. In Fig. 7, a typical curve of the iteration process is shown. Note that the relatively high resulting value of ER-α correlation time of about 40 s definitely indicates a very good separation possibility of the DGFRS2 setup.

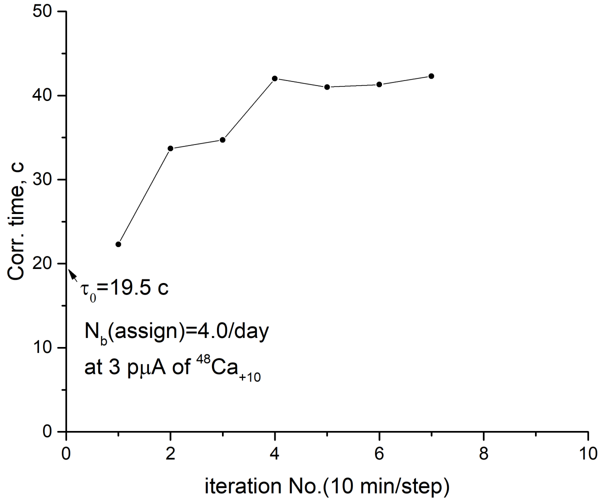

Fig. 7. The flexible algorithm iteration (C++ onTimer event) process for ^{242}Pu+^{48}Ca→*Fl reaction.

4. Summary

The new analog spectrometer of the Dubna Gas-Filled Recoil Separator No. 2 has been designed and successfully tested in ^{48}Ca induced complete fusion nuclear reactions at new DC-280 ultra-intense cyclotron. For the first time:

— a flexible algorithm for the method of active correlations has been tested in ^{243}Am(^{48}Ca, $3n$) ^{288}Mc and ^{242}Pu (^{48}Ca, $3n$) ^{287}Fl reactions;

— a low-pressure ΔE proportional chamber has been applied to discriminate SHE recoil nuclei with respect to background products;

— in the ^{242}Pu (^{48}Ca, $3n$) ^{287}Fl reaction, the spectrum of evaporation residues of registered energy is in good agreement with the calculated one for statistics of 100 events.

— the whole spectrometer and its subsystems were tested at ultra-high intensity up to 5 pμA.

We plan to apply the described detection system in the nearest future ^{238}U+^{54}Cr experiment at DC-280 cyclotron.

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