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EXPERIMENTS WITH GABRIELA DETECTOR SYSTEM

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For several years, more dozen experiments was carried out on SHELS (**S**eparator for **H**eavy **EL**ements **S**pectroscopy), aimed to investigation of characteristics of heavy elements and discover new isotopes. Perfect data acquisition system GABRIELA allows to investigate single particle states behavior, as well as the structure of little known elements in the Z = 102–105 and N = 148–162 region. Complex of DSSSD detects 70% alpha particles and 90% spontaneous fissions; a system of 5 coaxial Ge-detectors in 4π geometry has efficiency of gamma-quanta registration of 34–14% by scale ~ 100–1000 keV.

Keywords: SHELS/VASSILISSA, heavy elements, spectroscopy.

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1. Separator for Heavy Elements Spectroscopy (SHELS)

Flerov Laboratory of Nuclear Reactions (FLNR) at JINR is well-known in researches of heavy and superheavy elements (SHE). There are synthesized new elements with Z = 113–118 and a lot of isotopes of SHE with Z = 104–118. The last chemical element in Mendeleev table was named Oganesson (118, Og) in honor of academician Yu. Ts. Oganessian.

Studies of reaction products and their levels structure are produced via VASSILISSA [1] set-up. Due to upgrades of VASSILISSA at 2013 years, the kinematic separator was remade in velocity filter SHELS [2], thereby a yield of facility is increased in times.

SHELS consists of the following elements (fig. 1):

- Target wheel: radius is 12 cm. The metal wheel divided by segments. In each segment was implanted target's substance on 1.5-2 μm Ti foil.
- Two triplets of quadrupole lenses: maximum field gradient is 13 T/m, effective length of 38 cm and aperture radius of 10 cm.
- Two high voltage electrostatic deflectors: effective length of 65.7 cm, distance between plats is 10–20 cm, maximum field gradient of 40 kV/cm and rated deflection angle is 8°.
- Three dipole magnets: effective length of 59.7 cm, dipole aperture of 13.5 cm, maximum field gradient is 0.8 T. Two magnets have rated deflection angles of 21.8°, and one of 8°.
- Time of Flight system (ToF).
- Detector system GABRIELA.

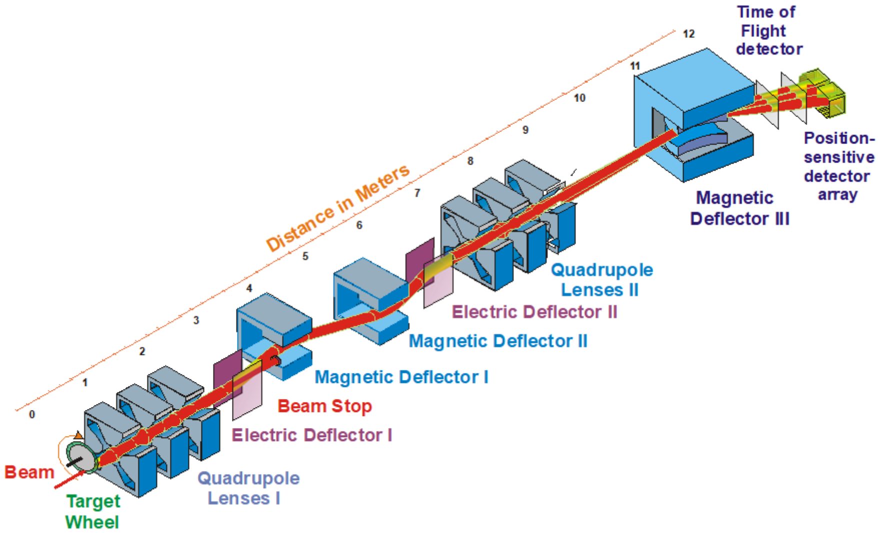

Figure 1. Separator for Heavy Elements Spectroscopy

The accelerated beam provides by the U-400 cyclotron, its intensity 0.5–1.5 μpA in depends of study reactions. There are use projectiles from ^{22}Ne to ^{54}Cr. Efficiency of the transmission of recoils nuclei (ε_{tr}) through the facility reaches 45%. This value is different for various asymmetric reaction, as an example, the reaction of ^{22}Ne + ^{197}Au has ε_{tr} = 6.5%. If compared to ε_{tr} from old facility, its value was 3% (tab. 1). For other reactions ε_{tr} were notably changed.

Table 1. Efficiency of the recoils nuclei transmission (ε_{tr}) for VASSILISSA and SHELS

Reaction	**E_{beam}, MeV**	**Target thick., mg/cm^2**	**ε_{tr}, % VASSILISSA**	**ε_{tr}, % SHELS**
$^{22}Ne(^{197}Au,4n)^{213\text{-}215}Ac$	120	0.25	3	6.5
$^{22}Ne(^{198}Pt,5\text{-}7n)^{213\text{-}215}Ra$	115-125	0.25	3.5	3.5–5
$^{50}Ti(^{164}Dy,4\text{-}5n)^{209}Ra$	240	0.3	30	40
$^{50}Ti(^{208}Pb,2n)^{256}Rf$	237	0.36	25	20–40

2. Detection system

After selection in separator the interest products pass through a ToF detector composed of 2 or 3 emissive polycarbonate foils and 4 large-size ($70\times90mm^2$) microchannel plates (production by BASPIK). Foils have gold or graphite sprayed on it, and installed in metal frame. Thickness of polycarbonate is 0.4 mg, gold of 0.35–0.45 mg. Active area of plate is 86×66 mm, thickness of 1 mm, as well as pore size is 15 μm, a channel pitch of 19 μm and bias of 8°. A new ToF detector has more compact geometry. The main purpose of this system is giving a marker to the recoil nucleus, which used in data analysis.

In the next step, the particles enter the detection system. The separator can use two kinds of detector arrays:

- Neutron barrel (fig. 2).
- Gamma Alpha Beta Recoil Investigation with the Electromagnetic Analyzer (GABRIELA) (fig. 3).

The assembly of the focal detector for neutron barrel is positioned in a cylindrical vacuum chamber surrounded by three layers of neutron counters (^3He at pressure of 7 atm) placed in the volume of the retarder. The neutron assembly is surrounded by six plates of Ba-doped polyethylene to protect against background neutrons [3]. The TKE of fragments and their half-lives were measured in the experiment. The signals from fission fragments trigger interrogation of the neutron counters positioned around the vacuum chamber of the focal detector, ensuring reliable measurements of the number of neutrons accompanying each fission event. The average lifetime of fission neutrons in the detector is 23–30 μs, and the efficiency of single neutron registration is 43–45% (measurements are made using a ^{248}Cm source). It should be noted that the background conditions were quite favorable in all experiments: the count of background neutrons in the room with detectors did not exceed 100 random counts per second.

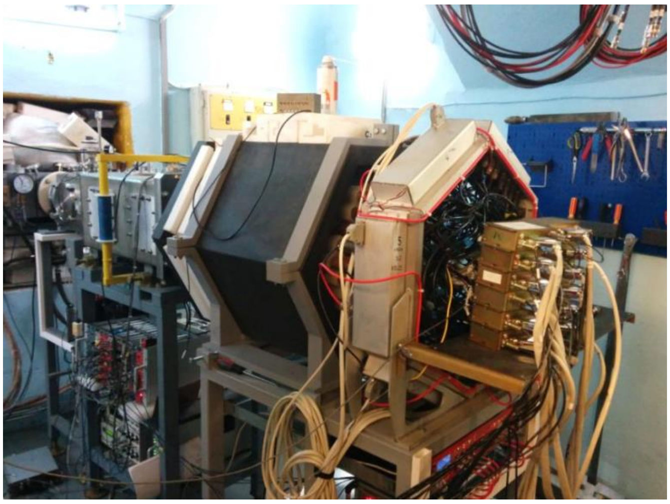

Figure 2. Neutron barrel

The GABRIELA [4] detects the evaporation residues with their subsequent α decay or fission, as well as γ-rays, X-rays and conversion electrons. At 2013-2015 for GABRIELA was upgraded, and now it has another view (fig. 3). New content includes of the one box of DSSD and 5 Ge-detectors, which demonstrate more efficient work, than one Si-box and 7 Ge-detectors (in old version).

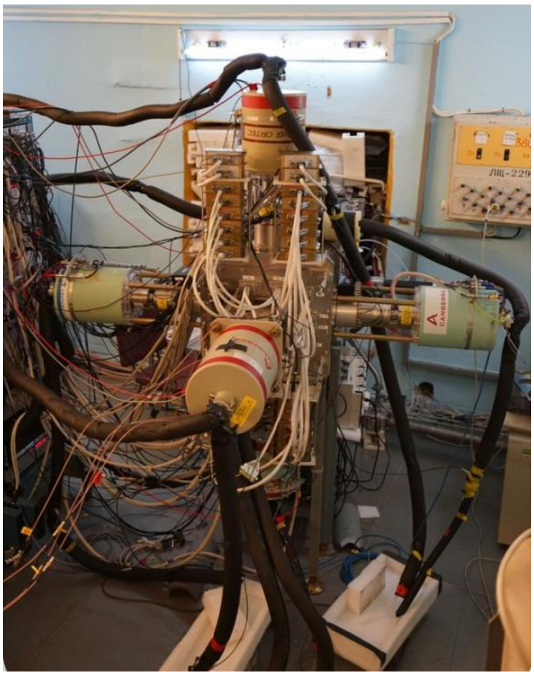

Figure 3. GABRIELA

The box of detectors consists of large $10\times10 cm^2$ double-sided silicon strip detector (DSSSD) (fig. 4), 128×128 strips (16384 pixels) and thickness is 500 μm. This is focal plane detector, which surrounded of 8 plats 50×60mm2 DSSD (thickness of 700 μm), 32×32 strips (4096 pixels). Alpha particles registration efficiency ε_α = 70% and the resolution energy is 15-20 keV for α in the range of 5–7 MeV.

Figure 4. Focal detector 128×128 strips

The Ge array consists of a large Clover installed just behind the focal plane DSSSD and 4 coaxial Ge detectors forming a cross around the DSSD. All Ge detectors are equipped with BGO shields. This configuration is more efficient! The calibration of the Ge detectors was performed using standard sources such as ^{152}Eu and ^{133}Ba. Registration efficiency is 38–14% by gamma-quanta energy scale from 100 keV to 1000 keV.

3. Conclusions

As for recoils registration efficiency (ε_{reg}), then achieved good results. In hot fusion reaction ^{40}Ar + ^{180}Hf formed compound nuclei ^{220}Th*, by energy beam 220 Mev (fig. 5). There was integral flux of $6.2\cdot10^{17}$ particles. Value of registration efficiency ε_{reg} was calculated by peak of ^{215}Ac, which created through *p*4*n*-channel. Nuclide of ^{215}Ac has short half-life time 0.17 s, it was convenient to used for calculate. Ratio of number of Rec-α correlations by number of α-particles from ^{215}Ac peak it is ε_{reg} = 87.4%.

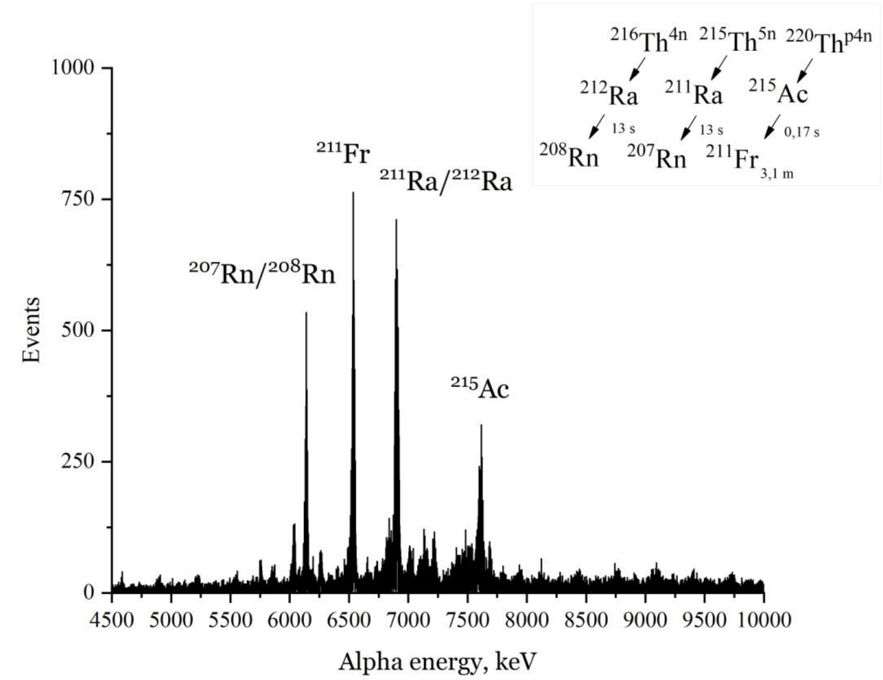

Figure 5. Spectrum of α-particles decays of Th isotopes

In experiments was studied heavy nuclei with Z=102–106 (tab. 2). System of detectors demonstrated good performance.

Table 2. Experiments 2017–2019 years

Z	Reaction	Isotopes	Results
102	^{22}Ne+^{238}U ^{48}Ca+^{204,206,208}Pb	^{256}No ^{250}No, ^{252}No, ^{254}No	New metastable states of No isotopes.
104	^{50}Ti+^{206,208}Pb [3]	^{254}Rf, ^{255}Rf,^{256}Rf, ^{257}Rf	New information about levels structure.
105	^{50}Ti+^{209}Bi [5]	^{256}Db, ^{257}Db, ^{258}Db	More chains of decay Db isotopes and 3 events "fast" fission from ^{258}Rf (*p*0*n*).
106	^{54}Cr+^{208}Pb	$^{262-xn}$Sg	Test for future experiments with Cr beam.

The plans are another upgrade of the SHELS. Instead quadrupole lenses will be install lenses with more apertures of 300 mm. All Ge-detectors will be replaced on Clovers, and small DSSD on 10×10cm^2 DSSSD. Also diameter of target wheel will increase before 24 cm.

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