Application

"Development and application of new experimental methods at ACCULINNA-2 fragment separator"

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The application includes 5 publications.

In 2017, a new unique facility ACCULINNA-2 fragment separator at U-400M heavy-ion accelerator was launched at FLNR. Test experiments, performed for fragmentation of primary ^{15}N beam at the 2 mm beryllium target, demonstrated a good accordance between the design parameters and observed secondary RI beams. In 2018, methodical works aimed at to perform full scale experiments with RI beams ^{6}He, ^{8}He, ^{9}Li, ^{10}Be, etc. [1-5] were started.

Flagship experiment was aimed at the investigation of ^{7}H system and correlation measurements of its $t+4n$ decay products. For the ^{7}H states population the reaction ^{8}He (26 MeV per nucleon) + d $\rightarrow$ ^{3}He + ^{7}H was chosen. The coincidences of low-energy ^{3}He (E ~ 9÷30 MeV, $\theta \sim 8 \div 26^{o}$ in laboratory system, should be identified against intense ^{4}He background) and fast tritons (E ~ 70 ± 30 MeV) emitted in forward narrow cone $\theta \leq 6^{o}$ were a key factor for the ^{7}H observation. These tritons should be detected with quite a good angular $\Delta\theta \sim 0.5^{o}$ and energy $\Delta E/E \leq 2$ % resolutions. For this purpose, the triton telescope consisted of the 1.5 mm thick silicone double side detector and 4x4 array of CsI(Tl)+PMT detectors were developed. To improve determination of specific energy loss of reaction products in 20-μm silicon detectors, the map of their thickness was measured with 0.2-μm resolution and applied for dE energy loss correction (detailed review is in [3]). It allowed one to clearly identify by dE-E method with low threshold (~1 MeV per nucleon) all hydrogen, helium and lithium isotopes produced in ^{8}He + d interactions.

The possibility of studying ^{7}H in the ^{2}H(^{8}He,^{3}He)^{7}H reaction at ACCULINNA-2 fragment separator is based on:

(i) method of triton energy measurement with ^{3}He coincidence and true event selection in kinematic triangle;
(ii) using of thin cryogenic gas target providing high experimental resolution of ~ 1 MeV FWHM and well measured low background;
(iii) possibility of calibration of applied missing mass method in reference reaction ^{2}H(^{10}Be,^{3}He)^{9}Li with same setup;
(iv) high quality of RI beams at ACCULINNA-2 fragment separator (intensity, purity, focusing at physical target).

Using of developed methods, the series of 3 runs on ^{7}H was performed, accumulated high quality data are under analysis.

The second experiment at ACCULINNA-2 was aimed at studying low-lying states of ^{10}Li system produced in ^{9}Li(d,p)^{10}Li → n+^{9}Li reaction at 29 MeV per nucleon [4]. The key feature of this experiment was techniques of proton detection emitted at backward direction in laboratory system with coincidence of ^{9}Li and neutrons emitted at forward angles. For precise measurement of neutron energy and emission angle, specially created array of 44 mono-crystal stilbene scintillator detectors (80 mm in diameter with 50 mm thickness) [Bezbakh A.A. et al., Instrum. Exp. Tech., 2018 vol.61, No.5, p.631] was used. One of important elements in detection of ^{9}Li produced in ^{10}Li decay, was the developed ToF detector consisted of thin scintillator EJ-212 (125 μm) and four PMTs Hamamatsu R7600. This detector placed at distance of 39 cm downstream the physical target allowed one to identify the components of the secondary beam (d, ^{6}He, ^{9}Li and ^{12}Be) by dE-ToF method and separate incoming and decayed ^{9}Li. To check the experimental resolution of the whole setup and normalizing of ^{10}Li missing mass spectra, reference measurement of ^{6}He(d,p)^{7}He with triple coincidence p-^{6}He-n was performed. On the account of the collected statistics (about 400 triple coincidences p-^{9}Li-n) and good energy resolution of ~ 250 keV (FWHM) for ^{10}Li excitation spectra, one can assume to get new data on low-lying ^{10}Li states at ~ 0.5 and ~ 4 MeV.

The given experimental properties of ACCULINNA-2 facility provide the opportunity to observe new neutron-rich nuclei in the range $94 < Z < 107$ with neutron-rich beams in multi-nucleon transfer reactions at threshold energy of 4-6 MeV per nucleon. This area is not available with other methods, though it is of special interest as a means to move towards the island of stability. In the given methods, one can measure lifetime, fission barriers, and decay modes of such nuclei. Methodic approaches and aspects of production and study of such nuclei are reviewed in [5].

Development of experimental methods enables one to solve a number of tasks using radioactive beams at ACCULINNA-2 facility: production and study of light nuclei spectra ($Z = 1 \div 16$) lying beyond the boundaries of nucleon stability, investigation of rare decay modes, production of new heavy isotopes of elements ($Z = 94 \div 107$), and measurement of fission barriers of these nuclei in reactions of multi-nucleon transfers at the RI beams ^{9}Li, ^{10}Be, $^{14,16}C$, $^{17,19}N$, $^{20,22}O$, etc., up to $^{24,26}Ne$.

The stages of this work were presented at nuclear physics conferences and seminars in FLNR and JINR. The list of publications includes 5 articles published in «Nucl. Instrum. Methods in Phys. Res. B», «Bulletin of the RAS: Physics» and «Physics of Atomic Nuclei».

Chairman of STC FLNR ________________________

Secretary of STC FLNR ________________________

Appendix

List of publications

"Development and application of new experimental methods at ACCULINNA-2 fragment separator."

1. A. S. Fomichev, A. A. Bezbakh, S. G. Belogurov, R. Wolski, E. M. Gazeeva, A. V. Gorshkov, L. V. Grigorenko, B. Zalewski, G. Kaminski, S. A. Krupko, I. A. Muzalevskii, E. Yu. Nikolskii, Yu. L. Parfenova, S. I. Sidorchuk, R. S. Slepnev, G. M. Ter-Akopian, V. Chudoba, and P. G. Sharov,

"The first experiments with the new ACCULINNA-2 fragment separator",
Bulletin of the Russian Academy of Sciences: Physics, **83** (2019) 385–391.

2. G. Kaminski, B. Zalewski, S.G. Belogurov, A.A. Bezbakh, D. Biare, V. Chudoba, A.S. Fomichev, E.M. Gazeeva, M.S. Golovkov, A.V. Gorshkov, L.V. Grigorenko, D.A. Kostyleva, S.A. Krupko, I.A. Muzalevsky, E.Yu. Nikolskii, Yu.L. Parfenova, P. Plucinski, A.M. Quynh, A. Serikov, S.I. Sidorchuk, R.S. Slepnev, P.G. Sharov, P. Szymkiewicz, A. Swiercz, S.V. Stepantsov, G.M. Ter-Akopian, R. Wolski,

"Status of the new fragment separator ACCULINNA-2 and first experiments",
Nucl. Instrum. Methods Phys. Res. B **463** (2020) 504-507.

3. I.A. Muzalevskii, V. Chudoba, S.G. Belogurov, A.A. Bezbakh, D. Biare, A.S. Fomichev, S.A. Krupko, E.M. Gazeeva, M.S. Golovkov, A.V. Gorshkov, L.V. Grigorenko, G. Kaminski, O. Kiselev, D.A. Kostyleva, M.Yu. Kozlov, B. Mauyey, I. Mukha, E.Yu. Nikolskii, Yu.L. Parfenova, W. Piatek, A.M. Quynh, V.N. Schetinin, A. Serikov, S.I. Sidorchuk, P.G. Sharov, R.S. Slepnev, S.V. Stepantsov, A. Swiercz, P. Szymkiewicz, G.M. Ter-Akopian, R. Wolski, B. Zalewski,

"Detection of the low energy recoil ^{3}He in the reaction $^{2}H(^{8}He,^{3}He)^{7}H$",
Bulletin of the Russian Academy of Sciences: Physics, **84** (2020) 500-504.

4. A.A. Bezbakh, S.G. Belogurov, D. Biare, V. Chudoba, A.S. Fomichev, E.M. Gazeeva, M.S. Golovkov, A.V. Gorshkov, G.Kaminski, S.A. Krupko, B. Mauyey, I.A. Muzalevskii, E.Yu. Nikolskii, Yu.L. Parfenova, W. Piatek, A.M. Quynh, A. Serikov, S.I. Sidorchuk, P.G. Sharov, R.S. Slepnev, S.V. Stepantsov, A. Swiercz, P. Szymkiewicz, G.M. Ter-Akopian, R. Wolski, B. Zalewski,

"Study of ^{10}Li low energy spectrum in the $^{2}H(^{9}Li,p)$ reaction",
Bulletin of the Russian Academy of Sciences: Physics, **84** (2020) 491-494.

5. G. M. Ter-Akopian, Yu. Ts. Oganessian, A.A.Bezbakh, A. S. Fomichev, M. S. Golovkov, A.V.Gorshkov, S.A.Krupko, E. Yu. Nikolskii, S. I. Sidorchuk, S.V.Stepantsov, R.Wolski,

"Radioactive-ion beams for the fission study of heavy neutron-rich nuclei",
Physics of Atomic Nuclei, 2020, Vol. **83**, No. 4, 497–502.