Presentations by FLNR young scientists of the new results and proposals in the field of nuclear physics

1.

Precision mass measurement of the heaviest nuclei in Dubna FLNR

Aleksey Novoselov

A project of experimental setup for precise mass measurements of heavy and superheavy elements has been represented. Crucial parts of it are a cryogenic gas-filled ion stopping cell (Cryocell) and a multi-reflection time-of-flight mass-spectrometer (MR-TOF-MS). A detailed overview of the experimental setup parts planned for locating at the reconstructed cyclotron facility U-400R is given. The main parameters of complex are presented, and the short analysis of planned research field is given. The cryocell tests results and the current status of the described experimental setup as a whole are adduced.

2.

Intense metallic ion beams for SHE synthesis

Dmitriy Pugachev

The synthesis of new superheavy elements (SHE) with atomic numbers Z = 114–118 has been a remarkable achievement in recent decades. These elements were produced in complete fusion reactions involving ^{48}Ca projectiles and neutron-rich actinide targets such as ^{242,244}Pu, ^{243}Am, ^{249}Cm, ^{249}Bk, and ^{249}Cf. However, the synthesis of elements with Z > 118 necessitates the use of heavier projectiles, as the availability of target materials is constrained by reactor production capabilities. The anticipated cross-sections for Z = 119 and Z = 120 are significantly lower—approximately 10–20 times less than those for ^{48}Ca-induced reactions—underscoring the need for higher beam intensities and improved experimental efficiency.

To solve this problem a new cyclotron DC-280 was put into operation at the FLNR [2] with planned beam intensities of up to 10 pμA of ions with average masses (*A* ~ 50) that is one order of magnitude higher than those produced at the U-400 cyclotron up to now.

Presently, the DC-280 is equipped with the permanent magnet DECRIS-PM ECR ion source with operating frequency of 14 GHz [3], capable to provide the intense ion beams in the medium mass range, more than 20 pμA of ^{48}Ca for example.

To advance experiments aimed at synthesizing elements with atomic numbers Z > 118, it is necessary to utilize elements such as Ti, Cr, and others. Since these isotopes are typically available in the form of oxides or metals, introducing them into the ECR source plasma as neutral particles is a prerequisite for ionization. The production of accelerated beams from new isotopes requires optimization of the ECR source operating mode and the development of material feeding techniques. For rare isotopes, ionization efficiency is a critical factor. Long-term beam stability is also essential, as experiments on SHE synthesis typically require extended durations.

For production of ^{50}Ti and ^{54}Cr ion beams presently, we use MIVOC technique, which was successfully used at the U-400 cyclotron. At the DC-280 cyclotron the long term (about 2 months) experiment was performed with $^{54}Cr^{10+}$ beam, produced from the $^{54}Cr(C_5H_5)_2$ compound. The average intensity on the target was kept at the level of 2 pμA according to requirements of experiment with rather good stability.

For production of ^{50}Ti ion beams the same method was used with $(CH_3)_5C_5Ti(CH_3)_3$ compound. For the moment with the injected Ti beam of 5 pμA the accelerated beam reached up to 2 pμA.

Also, the test experiments on production of Ti ion beam using SF_6 plasma with titanium foil were performed. Up to 60 eμA of $^{48}Ti^{11+}$ were produced from the source for tuning, and then accelerated beam of $^{48}Ti^{10+}$ was produced with the intensity of 30 eμA and good stability.

Except the MIVOC technique for production of ions of solids we are also developing the inductive oven for DECRIS-PM source.

The report presents the current status of work on the production of metallic ion beams from the ECR ion source of the SHE factory using various methods.

3.

Current status and latest findings from the nuGEN experiment at Kalinin Nuclear Power Plant

Igor Vorobiev

Recently multi-nucleon transfer (MNT) reactions as an alternative approach to synthesize new nuclei are actively investigated at different scientific centers, including JINR. And such investigations of MNT reactions aiming to produce new isotopes of heavy and superheavy elements have been performing at Flerov Laboratory of nuclear reactions at modified CORSET setup [1]. With using of U-400 accelerator mass and energy distributions of reaction products already have been measured in the reactions 136Xe + 238U and 209Bi + 197Au, 208Pb, 232Th, 238U at the incident energy ≈ 8 MeV / nucleon in a selected angular range. Using ToF-ToF and ToF-E methods the mass and energy distributions of correlated fragments, formed in MNT reactions, have been obtained for the reactions 136Xe + 238U [2] and 209Bi + 238U. The heaviest transuranium primary survived and fissioning fragments formed by massive transfer of nucleons have been observed in these reactions.

[1] E. M. Kozulin et al., Instrum. Exp. Tech. 51, 44 (2008).
[2] E. M. Kozulin et al., Phys. Rev. C 109, 034616 (2024).

4.

Study of the properties of elements with Z≥100

Alena Kuznetsova

The paper presents the results of studies that were carried out on beams of accelerated ions of ^{40}Ar, ^{48}Ca and ^{54}Cr with targets of ^{206,207}Pb and ^{209}Bi.

At the SHELS [1,2] separator, using the SFiNX [3] detection system, the neutron multiplicity distribution for isotope of ^{260}Sg* ($\nu = 4.9 \pm 0.4$), which was formed in the complete fusion reaction ^{54}Cr+^{207}Pb. In the reaction ^{40}Ar+^{209}Bi, the formation of ^{246,247}Md nuclei and their decay modes (alpha, β (EC)), as well as the formation of ^{246,247}Fm nuclei in pxn reaction channels, were studied.

A new target of 480 mm diameter made of ^{206}PbS was tested at the GRAND [4,5] separator (SHE Factory [6]) using the GABRIELA [7] detection system. Large statistics on ^{252}No isotopes were collected.

[1] Yeremin, A.V., Popeko, A.G., Malyshev, O.N., et al. // Phys. Part. Nucl. Lett., 2015, V. 12, No. 1, P. 35.
[2] Yeremin, A.V., Popeko, A.G., Malyshev, O.N., et al. // Phys. Part. Nucl. Lett., 2015, V. 12, No. 1, P. 43.
[3] Isaev A.V., Yeremin, A.V., et. all. // ISSN 1547-4771, Physics of Particles and Nuclei Letters, 2022, Vol. 19, No. 1, pp. 37–45.
[4] Kuznetsova A.A. // Bulletin of the Russian Academy of Sciences: Physics, 2023, V. 87, No. 8, PP. 1105–1111.
[5] Yeremin A. V., Popeko A. G., Svirikhin A. I., et al. // Phys. Part. Nuclei Lett. 2024, V. 21, PP. 518–525.
[6] Gulbekian, G.G., Dmitriev S.N., Itkis M.G., // Phys. Part. Nucl. Lett., 2019, V. 16, No. 6, P. 866.
[7] Lopez-Martens, A. et al. (Gabriela Collab.) // Eur. Phys. J. A. 2022, V. 58, No. 7, P. 134.

5.

Stilbene-based neutron TOF-spectrometer

Anh Mai

Modular neutron spectrometer (MONES) in ACCULINNA-2 based on stilbene crystals in combination with 3-inch fast ET-Enterprise 9822B photomultipliers, was developed in accordance with the requirements of our recent research in studying the low-energy spectra of several unbound nuclear systems ^{10}Li, ^{7,9}He populated in transfer reactions [1–2]. Since the correlation between the incident neutron energy and the amplitude scintillator response is unsettled, the time of flight (TOF) method is routinely applied for neutron energy measurements. The neutron energy is obtained from the measured neutron flight time and its accuracy is entirely determined by the time resolution of scintillation detector. This work is devoted to the characterization of neutron TOF spectrometer, in terms of amplitude and time resolution, neutron/gamma separation performance and detection efficiency in the detector. The detector response to gamma-rays and neutrons were performed using Monte Carlo Geant4 simulations and compared with measured data. The first derivative of measured response by the use of gamma sources was to locate the Compton Edge position for amplitude calibration. The portable generator of “tagged” neutrons with energies of 14.1 MeV [3] was utilized for reconstruction the light out response to heavy ions (protons and alpha particles) and determining the neutron registration efficiency.

[1] A. A. Bezbakh et al., “Study of ^{10}Li low energy spectrum in the ^{2}H(^{9}Li,p) reaction”, Bulletin of the Russian Academy of Sciences: Physics 84, 491, 2020.

[2] M. S. Golovkov et al., “Observation of a positive-parity wave in the low-energy spectrum of ^{7}He”, Physical Review C, 109, L061602, 2024.

[3] N. Ruskov et al. “TANGRA-Setup for the Investigation of Nuclear Fission induced by 14.1 MeV neutrons”, Physics Procedia 64, 2015.

6.

Possibilities of producing medically relevant Auger electron emitter 195mPt

Alexander Madumarov

This work is related to obtaining nuclear data and developing methods for isolating promising isotopes for nuclear medicine. One of such radionuclides is Auger electron emitter ^{195m}Pt. Two approaches to obtaining the target radionuclide are considered: reactor and photonuclear. Determination of the productivity of the first approach was based on calculating the previously unknown cross section of the ^{194}Ir(n,γ)^{195m}Ir reaction. For this purpose, a radiochemical technique for separating carrier-free platinum from an iridium bulk was developed. Then we applied a Monte-Carlo simulation and a system of differential equations to assess self-shielding effect on resonance neutrons and thus determining the unknown cross sections. It was found that the formation of the target radionuclide on thermal neutrons is negligible, and for the first time the cross section on resonance neutrons of the ^{194}Ir(n,γ)^{195m}Ir reaction was estimated, which amounted to 2900 b. The second approach to photonuclear production of ^{195m}Pt involved irradiating a mixture of cisplatin and cryptomelane ($K_2(Mn^{4+},Mn^{2+})_8(0,OH)_{16}$ (KMn_8O_{16})) on the MT-25 microtron, where cryptomelane served as a recoil acceptor and higher specific activity was achieved due to the Szilard-Chalmers effect. A series of irradiations was performed using a set of targets with different cisplatin and cryptomelane ratios. The effect of the ratio on the efficiency of recoil collection and the yield of ^{195m}Pt was assessed.
