Status and Prospects of Radiochemical Research
at the Dzhelepov Laboratory of Nuclear Problems of JINR

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The report presents radiochemical research at the Dzhelepov Laboratory of Nuclear Problems of JINR (DLNP JINR) in nuclear medicine and astrophysics. The relevance and value of applications of radionuclides in nuclear medicine and of neutrino research and search for the dark matter are obvious. The report covers the methods for production of radiopreparations for spectrometric and analytical purposes, as well as for synthesis of radiopharmaceuticals.

The main radiochemical method developed for isolation of a wide range of radionuclides and their separation is the direct-flow scheme, consisting of several connected stages based on chromatographic columns: 1) isolating microquantity of radionuclides from macroquantity of target material; 2) separating from analogue elements; 3) conditioning. The methods have been developed for a number of radionuclides: Ac, Ra and other fission products from the Th target[1,2], Sc from the Ca target[3], lanthanides from the Ta target[4], Nb from the Mo and Zr targets[5], etc. An alternative way to obtain radionuclides was proposed and developed on the basis of novel types of radionuclide generators – reverse and reverse-tandem separation schemes. The methods were developed for pairs of radionuclides: ^{44}Ti ($T_{1/2}$ = 59.1 y) / ^{44}Sc ($T_{1/2}$ = 4.042 h)[6], ^{90}Sr ($T_{1/2}$ = 28.91 y) / ^{90}Y ($T_{1/2}$ = 64.05 h)[7], ^{172}Hf ($T_{1/2}$ = 1.87 y) / ^{172}Lu ($T_{1/2}$ = 6.7 d)[8], etc.

Also, conventional manufacture of radionuclide sources for classical nuclear spectroscopy should be noted. A large number of sources for alpha, beta and gamma spectroscopy were manufactured, which ensured a significant amount of experimental data. Radionuclide sources for low-energy electron spectroscopy at the ESA-50 facility can be given as an example, and they made it possible to achieve an energy resolution of several eV[9].

The methods for obtaining low-background materials with an ultra-low impurity content to search for rare processes and to provide technical support for low-background experiments are also considered. The basis of the method for obtaining ultrapure samples is chromatographic separation with reverse-current removal of impurities, as well as application and preparation of ultrapure reagents based on highly volatile liquids. A striking example is the production of kilograms of enriched ^{82}Se ($T_{1/2} = 9.6 \cdot 10^{19}$ y) in a highly dispersed elemental form with an impurity content at a level of tens of μBq/kg in order to search for the neutrinoless double-beta decay[10,11].

In addition, the methods for analysis of radiopharmaceuticals and their precursors are discussed, and also of purity of resulting radiopreparations and low-background materials. Studies of local nuclide environments were carried out via methods of hyperfine interactions (Perturbed Angular Correlations, PAC) and radioactive tracers. Both radionuclide and chemical purity were determined at a uniquely high level of sensitivity by inductively coupled plasma mass spectrometry (ICP-MS), instrumental neutron activation analysis (INAA) and gamma spectrometry in an underground laboratory[12,13].

In the near future, DLNP JINR is going to put into operation two new basic facilities: the LINAC-200/800 Electron Accelerator and a spectrometric cluster functioning in tandem with it. Moreover, the reconstruction of radiochemical laboratories at the DLNP Experimental Department of Nuclear Spectroscopy and Radiochemistry is expected to be completed, and specialized radiochemical rooms (classes 2 and 3) and “pure chemical” laboratories are to be commissioned. Radiochemical research at DLNP JINR is expanding through new areas: ICP-MS for determining ultra-low concentrations of substances, primarily radioactive Th, U and K; emission mode of Mössbauer spectroscopy for studying post-effects of radioactive decay in solids and autoradiolysis of radiopharmaceuticals (^{119}Sb ($T_{1/2}$ = 38.19 h), ^{161}Tb ($T_{1/2}$ = 6.89 d), ^{57}Co ($T_{1/2}$ = 271.74 d), ^{119m}Sn ($T_{1/2}$ = 293.1 d), etc.); the improved PAC method for studying the behavior of radiopharmaceuticals (^{111}In ($T_{1/2}$ = 2.8047 d), ^{152}Eu ($T_{1/2}$ = 13.517 y), ^{154}Eu ($T_{1/2}$ = 8.601 y), ^{172}Lu ($T_{1/2}$ = 6.7 d) etc.) and solids with isomers (^{111m}Cd ($T_{1/2}$ = 48.5 min), ^{199m}Hg ($T_{1/2}$ = 42.67 min), ^{204m}Pb ($T_{1/2}$ = 66.93 min)) in samples irradiated at the LINAC-200/800 in a minimally invasive way. ICP-MS and novel radiochemistry facilities, as well as the access to low-background measurements at underground laboratories, will enable the production of low-background materials for experiments in neutrino physics and astrophysics, and also the analysis of these materials at a level of μBq/kg and below.

A wide range of radionuclide generators is expected to be manufactured on the basis of long-lived parent radioisotopes (^{32}Si→^{32}P, ^{44}Ti→^{44}Sc, ^{68}Ge→^{68}Ga, ^{90}Sr→^{90}Y, ^{194}Hg→^{194}Au, ^{202}Pb→^{202}Tl, ^{227}Ac→^{227}Th→^{223}Ra, ^{229}Th→^{225}Ra→^{225}Ac, ^{237}Np→^{233}Pa, ^{238}U→^{234}Th, etc., about 40–50 radionuclides pairs) for the purpose of providing physical, chemical and radiopharmaceutical studies with radionuclides continuously. In radiopharmaceutics and spectroscopy, some methods for production of radiopharmaceuticals using accessible nuclear facilities are also intended to be developed.

1 A. Baimukhanova, et.al. Nuclear Medicine and Biology, 2022, V 112–113, P 35–43.
2 D. V. Filosofov, et.al. Radiochemistry, 2013, V 55, P 410–417.
3 E. S. Kurakina, et.al. Nuclear Medicine and Biology, 2022, V 104–105, P 22–27.
4 G. Marinov, et.al. Preprint JINR E6-2019-11, 2019.
5 V. Radchenko, et.al. Radiochimica Acta, 2016, V 104, P 625–634.
6 D. V. Filosofov, et.al. Radiochimica Acta, 2010, V 98, P 149–156.

7 A. Baimukhanova, Dissertation for the scientific degree of candidate of chemical sciences, D. I. Mendeleev Russian University of Chemical Technology, 2024.
8 J. Dadakhanov et.al. Radiochemistry, 2018, V 60, P 415-426.
9 A. Kh. Inoyatov, Dissertation for the scientific degree of doctor of physics and mathematics, JINR, 2011.
10 A. V. Rakhimov, et.al. Radiochimica Acta, 2013, V 101, P 653–659.
11 A. V. Rakhimov, et.al. Radiochimica Acta, 2020, V 108, P 87–97.
12 P. S. Fedotov, et.al. Talanta, 2019, V 192, P 395–399.
13 A. V. Rakhimov, et.al. Radiochimica Acta, 2015, V 103, P 673–678.