I. Preamble

The PAC thanks the organizers for the excellent work in preparing the documentation and presentations for the meeting.

The JINR Directorate proposed to appoint V. Nesvizhevsky as Chair of the 56th session of the PAC for Nuclear Physics.

JINR Director G. Trubnikov presented the report "Structure and main directions of JINR research. Scientific results in recent years and the development of JINR for 2024–2030".

JINR Vice-Director S. Dmitriev informed the PAC about the resolution of the 132nd session of the Scientific Council (September 2022) and the decisions of the Committee of Plenipotentiaries (November 2022).

II. Draft Seven-Year Plan for the Development of JINR for 2024–2030 in nuclear physics

At the session of the PAC, the detailed reports on the status and proposals for the Seven-Year Plan for the Development of JINR for 2024–2030 in the field of nuclear physics were presented by the directors of the laboratories: S. Sidorchuk (FLNR), V. Shvetsov (FLNP), V. Korenkov (MLIT), BLTP Deputy Director N. Antonenko, and Head of the Department of DLNP E. Yakushev.

Flerov Laboratory of Nuclear Reactions

The heavy-ion research in the Flerov Laboratory of Nuclear Reactions is aimed at completing the tasks outlined in two themes: "Synthesis and properties of superheavy nuclei, structure of nuclei at the limits of nucleon stability" and "Development of the FLNR accelerator complex and experimental setups (DRIBs-III)". By the beginning of the new seven-year period (2024–2030), the Laboratory has made significant advances in the major areas of research. IUPAP/IUPAC officially recognized the synthesizing of new elements of the Periodic table, namely Fl, Mc, Lv, Ts, and Og, by FLNR. Further studies required a drastic increase in the efficiency of experiments. For this purpose, the SHE Factory — a facility based on the high-current DC-280 cyclotron and the new-generation separators DGFRS-2 and GRAND (DGFRS-3) — was commissioned at JINR in 2020. Increased beam intensities, improved acceleration efficiency and transport of reaction products made it possible to carry out experiments on the synthesis of SHE at a sensitivity level corresponding to cross-sections of less than 100 fb. New isotopes and decay modes of known elements were discovered in the reactions of ^{48}Ca beams with Th, U, Pu, Am targets. 238 new events of the synthesis of superheavy nuclides were registered at the SHE Factory for the period from 2020 to 2022. It is three times more than in the entire history of research. Of particular relevance is the detection for the first time of the alpha decay branch of ^{268}Db and of the new isotope ^{264}Lr.

The first experiments are currently being conducted for studying the chemical properties of superheavy elements 112 (Cn) and 114 (Fl) using the GRAND separator. A number of gamma- and neutron spectroscopy experiments with a series of Rf and Fm isotopes were performed at the upgraded SHELS-GABRIELA setup. For the neutron-deficient ^{249}No isotope, first synthesized in the SHELS separator experiment in 2020, the half-life ($T_{1/2}$ = 38.1±2.5 ms) and the energy of α-decay (E_α = 9129 keV) were measured, the branching ratio for spontaneous fission was estimated (≤ 0.23%).

In 2017, the new fragment separator ACCULINNA-2 was commissioned. The facility was equipped with an RF-kicker and a zero-angle spectrometer, which allowed for a considerable increase in the intensity of secondary beams for studying light nuclei far beyond the line of beta-stability. Experiments were conducted for investigating the structures of nuclear systems, such as $^{6,7}H$, $^{7,9}He$, and ^{10}Li, beyond the limits of nuclear stability. The U-400M accelerator is being upgraded and will be recommissioned in 2023. The modernization is expected to improve the reliability and stability of the accelerator, as well as to increase the intensity of heavy ion beams. Expected beam parameters: ^{7}Li (39 MeV/A) 10 pμA; ^{11}B (33 MeV/A) 6 pμA; ^{15}N (51 MeV/A) 2 pμA. As the first experiment at the U-400M cyclotron, it is planned to continue studies of the ^{7}He structure in the $^{6}He(d,p)^{7}He$ reaction.

Currently, preparations are underway for the construction of the DC-140 cyclotron, intended for applied physics research (including radiation materials science, production of track membranes and studies of their application).

A project for upgrading the U-400 → U-400R accelerator and a new 1500-m^2 experimental hall has been prepared. The U-400R cyclotron will become the base facility of the new accelerator complex and will make it possible to smoothly vary the energy of accelerated beams in the range of 1–28 MeV/A and increase beam intensity up to uranium. The main tasks for the upgraded U-400R accelerator complex will be the synthesizing of new heavy isotopes, studying the mechanisms of their formation in multinucleon transfer reactions and their properties. The reconstruction of the accelerator is scheduled for the beginning of the upcoming seven-year period, and the commissioning of the experimental building is planned for 2025.

One of the essential tasks of FLNR is the synthesis of new elements 119 and 120 in such reactions as $^{54}Cr+^{248}Cm$ and $^{50}Ti+^{249}Bk$. The production cross sections of new isotopes are expected to be around 20 fb. At present, the production of high-intensity ^{50}Ti and ^{54}Cr beams is underway, so is the construction of a new superconducting 28-GHz ECR ion source.

To study the chemical properties of the heaviest known elements 113–115, a superconducting solenoid separator will be constructed at the SHE Factory. The facility will allow focusing the reaction products in the focal plane into a spot not exceeding 1 cm in diameter with their efficient isolation from the projectile beam. This will make it possible for the first time to carry out experiments with isotope lifetimes less than 0.5 s.

One of the top priorities during the next seven years is precise measurement of SHE isotope masses. For this purpose, FLNR is planning to construct a multi-reflection time-of-flight spectrometer with a resolution of 10^{-7}. The spectrometer will allow measuring the masses of new isotopes with an accuracy of about 30 keV, which is comparable to the accuracy of measuring the alpha-decay energy. Therefore, the measurement of the mass of one nucleus in the decay chain of the synthesized nucleus will provide accurate information on the masses of all isotopes in this decay chain. Alpha-, beta-, gamma-, and neutron spectroscopy of SHE isotopes is also of utmost importance in the SHE Factory research programme for the coming years.

Further experimental studies of the structure and mechanisms of production of nuclei near and beyond the limits of nucleon stability are planned in FLNR at the ACCULINNA-1, ACCULINNA-2 and MAVR setups. At the beginning of the new seven-year period 2024–2030, a cryogenic gas system will be installed in the focal plane of the ACCULINNA-2 fragment separator, which will allow the use of hydrogen, deuterium, and tritium in gaseous and liquid phases as targets for secondary beams.

Recommendation. The PAC heard with interest the report on the main achievements of FLNR for the period 2017–2023. The PAC supports the proposed strategy for the development of heavy-ion physics research in FLNR for 2024–2030. The PAC expects that its research areas will be represented in the form of themes and projects at the next meeting of the PAC for Nuclear Physics in June 2023.

Frank Laboratory of Neutron Physics

Nuclear physics research with neutrons in FLNP is carried out within the framework of the scientific theme “Investigations of neutron nuclear interactions and properties of the neutron”. Three projects are being implemented in the framework of the theme: TANGRA (study of reactions with neutrons from a D-T generator using the method of tagged neutrons), ENGRIN (study of prompt fission neutrons), and modernization of the EG-5 accelerator. Physics research within the framework of the theme can be conditionally divided into three areas:

– study of violations of fundamental symmetries in the interaction of neutrons with nuclei, obtaining nuclear data;

– study of the fundamental properties of the neutron, physics of ultracold and very cold neutrons;

– applied and methodological research.

Due to the current restrictions of work on external neutron sources, the regular operation of IREN for physical experiments has become extremely important. It will help to resume studies, traditional for FLNP, of the properties of excited nuclei, reactions with the emission of charged particles, and the physics of fission on resonant neutrons, and to conduct methodological developments aimed at discovering T-noninvariant effects.

For the new seven-year period 2024–2030, it is proposed to focus on solving the following physical problems in the field of neutron nuclear physics:

– comprehensive study of the process of nuclear fission: measurement of mass-energy and angular distributions of fission fragments, prompt neutrons and gamma rays; measurements of delayed neutrons and gamma rays; search for rare and exotic fission modes (ternary, quaternary, and quinary fission; fission into three fragments with comparable masses; pion production during fission, cold fragmentation, etc.); study and search for P-odd and T-odd effects in fission;

– study of the properties of neutron resonances; measurement of gamma-ray spectra for resonances with different spins, parities and angular momenta; study and search for P-even and P-odd effects in neutron resonances; search for p-wave resonances in which a violation of time invariance can be expected;

– obtaining data for nuclear engineering and astrophysics: measurement of integral and differential neutron cross sections, angular correlations in the energy range from cold neutrons to ~1 GeV;

– development and application of the method of tagged neutrons to study reactions of interaction of fast neutrons with nuclei;

– development and application of neutron and nuclear methods for elemental analysis and applied research: instrumental activation analysis; prompt gamma-ray activation analysis; elemental analysis with fast and tagged neutrons; elemental analysis of surface layers of solids;

– the development of a new UCN source at the IBR-2 reactor will be one of the main tasks in this field for the period 2024–2030. Its creation will make it possible to improve the accuracy of measuring the neutron lifetime, conduct research based on precision spectroscopy of the gravitational levels of neutrons, and improve the limitation on the electric dipole moment of the neutron.

Over the seven-year period 2024–2030, it is planned to increase the intensity of the neutron flux of the IREN facility up to $3 \cdot 10^{12}$ s^{-1} as well as to increase the beam current of the EG-5 accelerator to 50 μA and its energy to 4.1 MeV.

Recommendation. The PAC heard with interest the report on the main achievements of FLNP during the seven-year period 2017–2023. The PAC recommends continuing scientific research in the field of nuclear physics with neutrons using the FLNP neutron facilities, such as the IREN pulsed source of resonance neutrons, the IBR-2 pulsed reactor and the EG-5 electrostatic generator, by opening several new projects.

The PAC recommends considering the possibility of singling out the work on the development of IREN as an infrastructure project, given that this facility should become the base for research in nuclear physics at FLNP.

The PAC suggests hearing a proposal to extend the theme of scientific research and reports with proposals to open new projects within the framework of the theme at the next meeting in June 2023.

Meshcheryakov Laboratory of Information Technologies

The development of reliable network and information and computing infrastructure, as well as mathematical and software support for the research and production activities of the Institute and its Member States on the basis of the JINR Multifunctional Information and Computing Complex (MICC), including the “Govorun” supercomputer, is carried out within the theme “Information and computing infrastructure of JINR” and its project “Multifunctional Information and Computing Complex (MICC)”. The JINR MICC is a basic facility of the JINR computing infrastructure and plays a defining role in scientific research that requires modern computing power and data storage systems.

The MICC uniqueness is ensured by the consolidation of all state-of-the-art information technologies: from a network infrastructure with a bandwidth up to 4x100 Gbps and a distributed data processing and storage system based on grid technologies and cloud computing, to a hyper-converged computing infrastructure with liquid cooling for supercomputer applications.

Another activity of MLIT is related to the development and implementation of effective methods, algorithms and software for modeling physical systems, mathematical processing and analysis of experimental data for the successful implementation of the scientific programme by scientists of JINR and its Member States (within the theme "Methods, algorithms and software for modeling physical systems, mathematical processing and analysis of experimental data"). Modern research in the field of fundamental science based on new mathematical and numerical methods for modeling complex systems and processes, new software packages and systems for experimental data analysis are being developed using multicore and hybrid hyperconverged architectures of the JINR MICC. The most important tasks are the development of new data processing and analysis algorithms based on deep and machine learning, including artificial intelligence, and the development of modern Big data methods and algorithms for solving applied problems. Research in the field of quantum computing will be aimed at developing algorithms for the intelligent control of JINR physical experimental facilities and at optimizing the solution of resource-intensive problems. The development of the digital platform "JINR Digital Ecosystem", which integrates existing and future services to support scientific, administrative and social activities as well as maintenance of the engineering and IT infrastructures of the Institute, will provide reliable and secure access to various types of data and will enable comprehensive analysis of information. A distinctive feature of MLIT's activities is close cooperation with all JINR Laboratories, institutes of the JINR Member States and other countries.

Recommendation. The PAC heard with interest the report on the main achievements of MLIT for the seven-year period 2017–2023. The PAC fully supports the MLIT scientific programme related to the development of the themes "Information and computing infrastructure of JINR" and "Methods, algorithms and software for modeling physical systems, mathematical processing and analysis of experimental data". The PAC recommends hearing proposals to extend the themes of scientific research and reports with proposals to open new projects within the framework of the themes at the next meeting in June 2023.

Dzhelepov Laboratory of Nuclear Problems

Scientific research within the theme "Non-accelerator neutrino physics and astrophysics" is devoted to the study of rare phenomena associated with the weak interaction by the methods of modern nuclear spectrometry. The following research directions are distinguished within the framework of the theme:

– investigation of double beta-decay by different calorimetric and track calorimetric methods;

– search for the neutrino magnetic moment, neutrino-nucleus coherent scattering (CEvNS);

– investigation of galactic and extragalactic neutrino sources, diffusive neutrino cosmic background, search for exotic particles, search for sterile neutrinos;

– distant investigation of processes inside a nuclear reactor core using neutrinos;

– development of new methods for the detection of charged and neutral particles;

– development of modern radiochemistry for astrophysics and nuclear medicine.

Currently, the above problems are being investigated in seven major scientific projects. Neutrinoless double beta-decay is studied in the SuperNEMO, GERDA (LEGEND), and MONUMENT projects. Experiments with the reactor anti-neutrino: νGeN — search for the neutrino magnetic moment and neutrino coherent scattering; DANSS — reactor diagnostics and investigation of neutrino properties. Direct search for dark matter (EDELWEISS project) is extended to search for new physics with CEνNS (joint EDELWEISS/RICOCHET project). One of the main JINR projects — the BAIKAL-GVD project — is dedicated to deep-water investigations with the neutrino telescope on Lake Baikal.

The implementation of the theme is carried out using common approaches and available resources. In addition to the scientific personnel, the following resources are available to realize the scientific programme: the laboratory for the production and repair of semiconductor detectors; laboratory for the development and production of scintillation materials; radiochemistry sector, mechanical workshops, the group for computer support, the group of mass separators, and others.

The PAC is pleased to note that within the theme, there are the knowledge, personnel and capabilities to create world-class facilities, make measurements with them and obtain world-leading results. The PAC supports the general direction of the theme development, when the participation in prestigious international projects provides access to know-how for the development of home-based neutrino experiments.

The PAC supports the DLNP Directorate's proposal to reorganize the structure of the theme with the preparation of new joint larger-scale projects reflecting real involvement of personnel and resources. In addition to the BAIKAL-GVD project, the new proposed projects within the theme are:

– investigation of reactor neutrinos on a short baseline (RICOCHET, DANSS-2, and νGeN experiments);

– nuclear spectrometry for the search and investigation of rare phenomena (all double beta-decay related experiments and activities, search for dark matter by nuclear spectrometry methods, etc.);

– radiochemistry and spectroscopy for astrophysics and nuclear medicine.

Recommendations. The PAC heard with interest the report on the main work performed and achievements of DLNP for the seven-year period 2017–2023. The PAC recommends reorganizing the structure of the theme and presenting larger projects in neutrino physics and astrophysics at the next PAC meeting. The PAC underlines the importance of the efforts of DLNP to further improve the local infrastructure at JINR and on Lake Baikal.

Bogoliubov Laboratory of Theoretical Physics

Research in the field of low energy nuclear physics is carried out within the framework of the theme “Theory of nuclear systems”. The works present the main research directions: structure of nuclei far from stability, structure of superheavy nuclei, nucleus-nucleus collisions at low energies, fusion and fission dynamics, nuclear reactions of astrophysical interest, few-body systems, nuclear dynamics at relativistic energies, properties of hot and dense nuclear matter, nonlinear quantum processes in strong polarized electromagnetic fields. Research in the field of low-energy nuclear physics will be focused on the study of exotic nuclei in the regions of superheavy elements and light nuclear systems at the borders of stability and beyond, which is relevant for experimental research at the Superheavy Elements Factory of FLNR JINR and in other world research centers. The nuclear dynamics of fusion and fission will be studied taking into account cluster degrees of freedom. For the new seven-year period 2024–2030, it is planned to continue research in the field of nuclear theory, in particular, to establish a connection between microscopic self-consistent and phenomenological models of the nucleus. It is planned to use energy density functionals to describe the nucleus-nucleus interactions, double γ-, β- and EC-decays of heavy nuclei. Models will be developed to predict the rates of various nuclear reactions for astrophysical purposes. Nuclear reactions in the stellar environment will be studied by the methods of the few-body theory and the theory of open quantum systems. The mechanisms of transfer of nucleons and/or clusters between nuclei, and of the decay of a nucleus in the field of another one, will be analyzed.

The PAC supports the continuation of the nuclear theory research under the ongoing theme, which should reflect a complex and broad approach to various aspects of nuclear structure and nuclear reactions and correspond to the experimental programme of JINR. For a better organization of research, the theme should consist of four projects: “Microscopic models for exotic nuclei and nuclear astrophysics”, “Low-energy nuclear dynamics and properties of nuclear systems”, “Quantum few-body systems”, and “Relativistic nuclear dynamics and nonlinear quantum processes”. The PAC also appreciates the BLTP educational activities and the connection between theoretical studies and the JINR experimental programme.

Recommendation. The PAC appreciates the results obtained in the main areas of research and recommends the extension of the theme “Theory of nuclear systems” until 2030.

III. Next meeting of the PAC

The next meeting of the PAC for Nuclear Physics will be held on 29–30 June 2023. Its tentative agenda includes:

- reports and recommendations on the themes and projects to be completed in 2023;
- scientific reports;
- poster presentations of new results and proposals by young scientists in the field of nuclear physics research.

V. Nesvizhevsky

Chair of the PAC
for Nuclear Physics

N. Skobelev

Scientific Secretary of the PAC
for Nuclear Physics