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JINR LONG-TERM DEVELOPMENT STRATEGIC PLAN UP TO 2030 AND BEYOND

Joint Institute for Nuclear Research

JINR LONG-TERM DEVELOPMENT STRATEGIC PLAN UP TO 2030 AND BEYOND

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JINR: YESTERDAY, TODAY, AND TOMORROW

The Joint Institute for Nuclear Research was established in 1956 with the aim of uniting the efforts of the Member States to study the fundamental properties of matter. The establishment of JINR was in line with the postwar desire of states to move to peaceful joint work and organizationally unite scientists from many countries to implement scientific research programmes of such a scale and complexity that are unattainable at a national level. Since its inception, JINR, as an international intergovernmental organization, has been called upon to play an integrating role both directly in scientific research and in training of highly qualified personnel, materializing the slogan: "SCIENCE BRINGS NATIONS TOGETHER".

The Institute has built a unique set of world-class experimental physics facilities: superconducting relativistic accelerator of nuclei and heavy ions Nuclotron; cyclotrons of heavy ions, U-400 and U-400M, with record-breaking beam parameters for experiments on the synthesis of superheavy elements and exotic nuclei; unique high-flux neutron pulsed fast reactor IBR-2. The JINR experimental scientific programme is based on a brilliant school of theoretical physics, a vast experience in the methodology of physics experiments, and on the latest achievements in the field of Information Technology, including grid, cloud, and supercomputer technologies. A number of projects have been implemented to develop the research infrastructure of the JINR Member States, to build new facilities, and to elaborate scientific programmes for them. JINR's intellectual and material contribution to large international projects at CERN, in the United States, Germany, Japan, Italy, China, and France has played a key role in achieving the world-class results of these collaborations, which have enriched the repository of knowledge of mankind. Several generations of highly qualified scientists and specialists from many countries, primarily from the JINR Member States, were formed at JINR and currently work successfully in leading scientific organizations and universities around the world.

JINR today is one of the top three largest international intergovernmental organizations in terms of the number of staff and ranks sixth among them in terms of funding. The Institute is actively developing. The mega-science project NICA, a unique experimental facility based on the relativistic heavy-ion collider, is under construction; the SuperHeavy Element (SHE) Factory has been put into operation as the basis of the DRIBs-III project; the largest deep underwater neutrino telescope in the northern hemisphere on Lake Baikal, a key element of the Global Neutrino Network, is being rapidly built; the spectrometer complex at the IBR-2 reactor is being upgraded; the project of a new neutron source with parameters exceeding the world's pulsed neutron sources is being elaborated; one of the largest and most productive heterogeneous information and computing complexes in Russia and Eastern Europe is continuously expanding its capacity.

The JINR experimental base makes it possible to carry out not only advanced fundamental but also applied research in the field of condensed matter physics, radiobiology, radiation and space medicine, materials science, low-temperature physics, geophysics and geology, palaeontology, archaeology, studying the structure and properties of nanosystems and new materials, biological objects, the development of new electronic, engineering, nuclear power and safety, bio- and information technologies, following carbon-free trends.

Over the past decade, updating and developing the experimental base has been the main priority of the Institute, which is reflected in the seven-year plans for the JINR development for 2010–2016 and 2017–2023. The Strategy for the further development of JINR until 2030 and beyond, along with the improvement of the research infrastructure and the formation of an advanced multidisciplinary scientific programme, is aimed at integrated development of intellectual potential and at the strengthening of the Institute as an international intergovernmental scientific organization.

The mission of JINR in the context of science globalization is to achieve international leadership of JINR Member States in specialized areas of science and technology for the Institute through the integration of their intellectual, financial, and material resources. The Institute's development relies on national scientific schools and cultural traditions with the aim of obtaining scientific results, which are usually unattainable, within the framework of national institutions and other forms of international scientific cooperation, and of training highly qualified personnel for JINR Member States and partners.

Addressing these challenges is achieved through the development of a permanent platform for an international exchange of knowledge and technologies: the simultaneous implementation of many projects of various scales and nature, ensuring a balance of interests of the Member States in the choice of topics and forms of cooperation, guaranteeing continuity and thematic flexibility of the scientific programme in a strategic perspective. Assistance in the transformation of the results of the creative work of scientists and specialists into innovations, dissemination of information about the achievements of modern science and their impact on the socio-economic development of mankind to the public are crucial to attaining the Institute's objectives.

Committee of Plenipotentiaries
of the Governments
of the JINR Member States

FOREWORD

The Joint Institute for Nuclear Research presents the JINR Long-Term Development Strategy up to 2030 and beyond (LTDS). JINR sees itself as part of a large global family of unique laboratories around the world. Membership in this club obliges the Institute to provide the highest quality of the scientific agenda, vision of distant horizons, wise planning, and to value cooperation – but most importantly – people who do science. For this reason, conceptual work on a Scientific Long-Term Plan (SLTP) as a nucleus of LTDS was started in 2017: we established an International Working Group of worldwide recognized experts. Visions of this Group and six Working Sub-Groups determined the subfields of modern Science to be addressed in the future at JINR: Low-Energy Nuclear Physics, Relativistic Heavy-Ion and Spin Physics, Particle and High-Energy Physics, Neutrino and Astroparticle Physics, Condensed Matter and Neutron Nuclear Physics, Radio- and Astrobiology, Nuclear Medicine, Theoretical Physics, Information Technologies & High-Performance Computing. The Sub-Groups had an ambitious and exciting challenge: to outline the most exciting physics today and tomorrow.

This document has already started its way to implementation: in 2020 the JINR International Scientific Council and the Committee of JINR Member States Plenipotentiaries approved the SLTP Concept and charged the directorate to continue the strategic planning towards development of the next JINR 7-year plan.

JINR's strategy is designed to strengthen our common global scientific family. The LTDS will create sibling connections both to national research strategies and priorities of the JINR Member States and to the European Strategy for Nuclear Physics, the European and Worldwide Particle Physics Strategies, as well as to Global Strategies of Astroparticle Physics, Biophysics, Neutron Research and Big Data Initiatives.

The LTDS drafting has touched not only "pure science", but also important aspects of scientific cooperation, human resources, social environment, digitalization and administrative issues, innovation policy, monitoring and indicator system: all essential issues define a modern dynamic international intergovernmental scientific organization. All this was the subject of very active discussions of the JINR Working Group for Expertise and Analysis in 2020.

On behalf of the JINR Directorate, I would like to thank everyone from JINR Member States and all over the world involved in drafting and approval of this document. Now we are facing a new challenge – by joint efforts we will move towards these ambitious and bright landmarks. We look forward to your continued support.

JINR Director
Grigory Trubnikov

SCIENTIFIC LONG-TERM PLAN: EXECUTIVE SUMMARY

PREAMBLE

The strategy for the further development of JINR until 2030 and beyond as an international intergovernmental scientific research organization is based on the Charter-defined main objective of JINR, which is to unify the efforts, scientific and material potentials of the Institute Member States for investigations of the fundamental properties of matter.

The goal of this Long-Range Plan is to assure that JINR is attractive for the JINR Member States (scientists, engineers, technicians and students, member-state governments) as well as for the international community of scientists in the coming future. This strategy asks for consolidation and strengthening of the unique JINR status as one of the few major international organizations where basic research has been carried out successfully and efficiently at the world's top level in an unprecedented wide range of important scientific directions during the last 65 years.

This report on the Strategy for a Long-Range Plan is the fruit of intense discussions of JINR scientists with worldwide recognized experts of their research domain.

The JINR Strategic Long-Range Plan sees a vigorous determination of this Institute to stay at the forefront of Science in the chosen fields of Basic Research. This plan will continue to be an integral part of the European Strategy for Nuclear Physics, of the European and Worldwide Particle Physics Strategies, as well as of Global Strategies of Astroparticle Physics, Biophysics, and Neutron Research.

Based on this work, the following plan emerged where both new facilities and those already under construction have been positively evaluated, such as:

- Superheavy Element Factory,
- Flagship facility NICA with its fixed target programme and the collider mode for Relativistic Heavy-Ion collisions,
- NICA facility for Spin Physics with polarized beams,
- Deep underwater neutrino telescope Baikal-GVD,
- New Pulsed Neutron Source DNS-IV, based on a high-intensity pulsed neutron reactor IBR-3 with Np-237 core,
- Irradiation facilities for materials science and radiobiology,
- New Rare Isotope Collider Facility,
- New Centre for Innovation Research in Nuclear Technologies, including radiobiology and beam therapy;
- Continuously expanding Supercomputer and dynamically growing IT platform, which responds to the rapidly developing IT world.

JINR has a long record of successful participation in forefront external experiments in Relativistic Heavy-Ion Physics, Particle Physics and Neutrino Physics. The proposed plan foresees a continuation of participation in experiments at accelerator centres around the world (CERN, BNL, DESY, FAIR, GSI) and Neutrino experiments that provide unique conditions to perform studies in the fields of relativistic heavy-ion physics and spin physics. However, the key factor must be a mutual benefit from the exchange of data, of new scientific technologies and of theoretical know-how. JINR participation must be visible and will depend on the discovery potential of the experiments and of JINR researchers playing a leading role.

EXECUTIVE SUMMARY

A successful future of JINR is based on JINR's unique traditions and its selection of scientific research directions at the forefront of basic research, in a spirit of international collaboration and competition and with the openness to structural and methodical changes in multidisciplinary collaborations.

As outlined in this report, vast expertise and knowledge have been accumulated in the Laboratories of JINR during the last decades. Although collaboration between the Laboratories was always a highly important factor for development of new scientific directions and particular projects at JINR, the exchange of expertise and knowledge between the JINR Laboratories must be strengthened by increased cross communication between them and aligned coherently for meeting new challenges of Science and for staying competitive in the world.

Successful implementation of an ambitious Long-Term Programme requires close collaboration between Laboratories and coordination of human and material resources. In the face of fierce competition, new digital and information approaches are needed, and the creation of centres for the development of advanced detectors and the frontier accelerator technologies is required. New JINR Centres of Competence for Sensors/Detectors and Micro-electronics must be developed. A new JINR Centre of Competence for Accelerator Science and Technology must be created, which covers a wide range of areas JINR scientists will be working in: from keV to GeV energy range, wide spectra of ion beams, electron beams from keV's up to GeV's, from cyclotrons, linacs, synchrotrons to new modern accelerator technologies and materials, coupled to modern digital and information approaches. There is plenty of expertise in the different laboratories, and the new centre will coherently house all that, and allow JINR with its ambitious goals to actively participate in global research facilities.

With this spirit and the newly developed Centres of Competence for Sensors/Detectors and Micro-electronics and for Accelerator Science and Technology, JINR can move forward as one of the leading research centres of the world.

The programme of the long-term development of JINR outlined in this report is dedicated to ensure attractiveness in all possible aspects: highest-quality science, education, innovations, atmosphere of mutually beneficial scientific creativity, comfortable and secure living conditions. The JINR Member States should see clear advantage and benefit from integration of their financial and human resources within JINR to participate in research activities they could not do or afford alone.

JINR has chosen to work on the forefront of several fields of Science being internationally recognized as highly important and challenging strategic directions of research at the forefront of all of these selected fields.

Most research is being pursued in experiments at the JINR site, others require participation in international collaborations off-site. Here is the list of research topics pursued by JINR today and planned for the future:

- Low-Energy Nuclear Physics,
- Relativistic Nuclear and Spin Physics,
- Particle and High-Energy Physics,
- Neutrino and Astroparticle Physics,
- Condensed Matter and Neutron Nuclear Physics,
- Radiobiology, Omics Technologies, Astrobiology and Radiation Medicine,
- Theoretical and Mathematical Physics, Cosmology,
- Information Technologies & High-Performance Computing.

LOW-ENERGY NUCLEAR PHYSICS

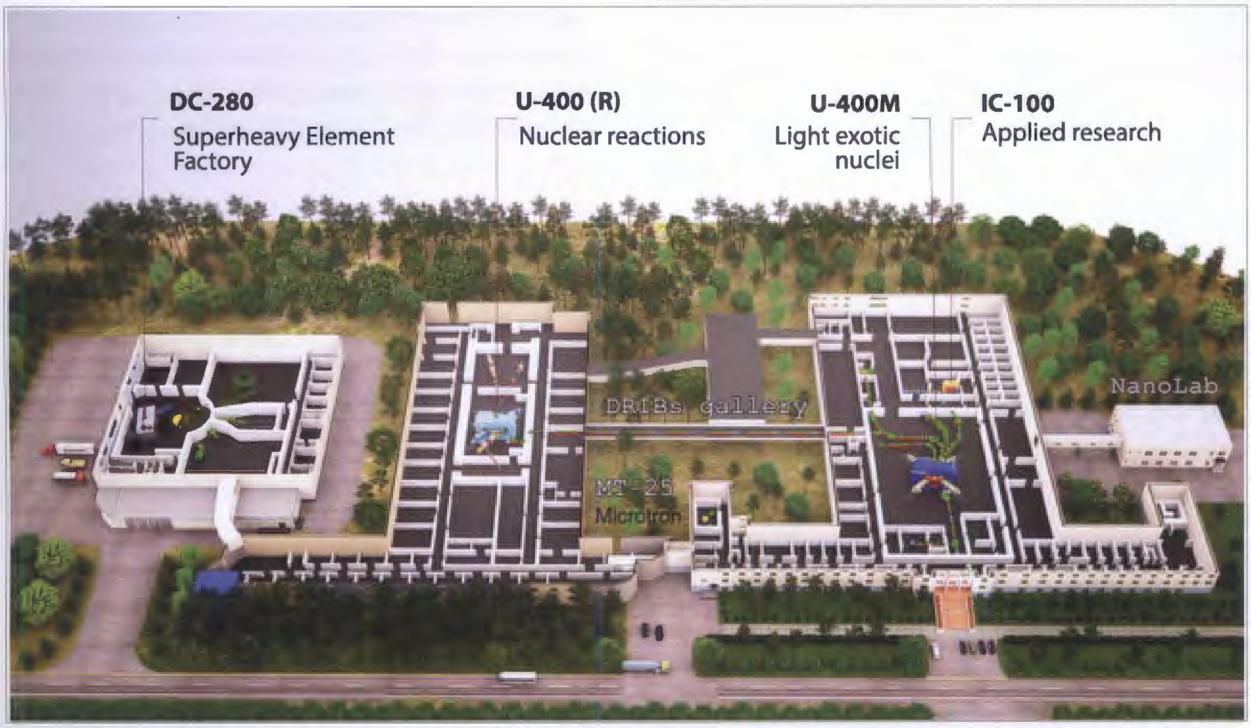
Since its foundation, the main direction of scientific research at the Flerov Laboratory of Nuclear Reactions (FLNR) of JINR has been the worldwide recognized synthesis of new elements of the Mendeleev Periodic Table, the study of their properties, via nuclear spectroscopy (α-, β-, γ-spectroscopy) and via chemical analysis as well as extensive study of various nuclear reactions leading to formation of new yet-unknown nuclei.

The pursuit of this research will be the main part of FLNR's programme for the next decade: looking for the limits of the existence of nuclear matter by focusing on the boundaries of the island of stability of SuperHeavy Elements (SHE), the region of the nuclear map where long-lived SHE isotopes could be found. For that endeavour, a SHE Factory is being constructed based on the DC-280 heavy-ion cyclotron, the world's top accelerator among others of the same type. Substantial increase (more than a factor of 10) in the efficiency of experiments is needed for the synthesis of the heaviest elements 119 and 120 and for the study of nuclear and chemical properties of already known elements.

Measuring the masses of SHE at FLNR is planned with the use of a pre-separator followed by a cryogenic gas ion catcher and a time-of-flight mass spectrometer.

The construction of a specialized building complex comprising radiochemical laboratories of Class 1 for the manufacture and regeneration of highly radioactive targets is foreseen, completing the SHE Factory.

Another scientific avenue in the field of SHE is emerging: Multi-nucleon transfer reactions in near-barrier collisions of actinides are promising in synthesizing new neutron-rich isotopes of heavy and Superheavy Elements up to the beta-stability line. The modernized U-400R accelerator complex will provide necessary conditions for in-depth study of these and other low-energy nuclear reactions with heavy ions.



The layout of the FLNR accelerator complex

NUCLEAR PHYSICS WITH BEAMS OF RARE ISOTOPES

The aim of the Rare Isotope Beam (RIB) studies is to provide full knowledge of the nuclear chart from nuclear-stable isotopes to the limits of nuclear structure existence.

Within this long-range programme, JINR looks at another promising Nuclear Physics programme, heavily promoted in the world of nuclear physics in the last 3 decades. Beams of rare isotopes far off the line of stability would be complementing the study of Superheavy Elements pursued at FLNR, and allow JINR staying at the forefront of nuclear physics and providing state-of-the-art research in nuclear physics for the Member States of JINR and the international nuclear physics community.

The JINR FLNR will ensure the continuation of the experimental research in the field of light exotic nuclei located at the borders of nuclear stability, with studies of nuclear haloes, neutron skins, cluster states, of exotic multi-neutron decays (2-nucleon virtual states, $2n$- and $4n$-radioactivity), two-proton radioactivity, search for new magic numbers and spectroscopy of exotic nuclei, and even reactions with halo nuclei. This experimental programme will be realized in the main at the fragment separator ACCULINNA-2 at the U-400M cyclotron complex.

Encouraged by leading international scientists of the nuclear physics community, JINR has proposed to develop and build a powerful Rare Isotope Collider Facility (RICF) covering a broad range of topics of modern nuclear physics with intense secondary RIBs (new isotope synthesis and production, its masses, lifetimes and decay modes, nuclear reactions and spectroscopy).

The RICF concept combines in-flight production of RIBs by projectile fragmentation technique (primary beams up to uranium with energy ~100 AMeV), stopping RIBs by gas catcher, reacceleration by LINAC–synchrotron combination, storage rings, usage of reaccelerated RIBs for reaction studies. The emphasis of the project is storage-ring physics with ultimate aim of electron–RIB scattering studies in collider experiments. The realization of this new advanced programme may lead to a necessity to reconsider the existing JINR structure and creating the new laboratory or the interlaboratory centre.

Empowered by the SHE Factory of FLNR and later by the RICF complex, JINR at Dubna will be a worldwide unique laboratory complementing the top nuclear physics facilities at FAIR/GSI in Germany, RIKEN in Japan, FRIB in the USA and GANIL/SPIRAL 2 in France.

RELATIVISTIC HEAVY-ION PHYSICS AT NICA

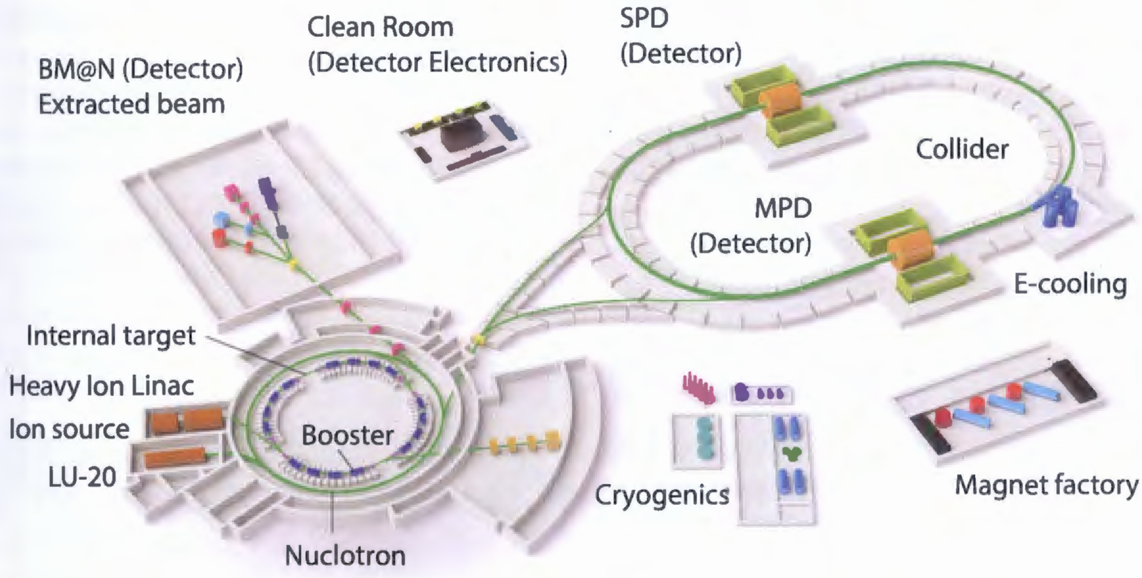
From the beginning of the relativistic nuclear research in the early 1970s, JINR has been an important player with its on-site programme at the Synchrophasotron, and then Nuclotron, and its participation in the heavy-ion programme at the CERN SPS first in WA98 and NA49/NA61, then in ALICE.

These activities have been the motivation and source for the Mega-Science project NICA and the Long-Range Plan presented below. The dominant tasks in the near and long-term future are:

a) The timely completion of the construction of the NICA project, its commissioning and a smooth operation.

b) Completion of the detectors, the BM@N, and the MPD at NICA and successful data collection over the decades to come.

c) After several years of running in the start version of MPD, an upgrade of the MPD detector is foreseen, responding to a possible increase in luminosity of NICA, and by adding detectors in the forward rapidities as planned in the original layout of MPD.



The NICA accelerator complex

d) Studies of possible future extension of NICA for acceleration of electrons, intense *p*-beams as well as of radioactive heavy nuclei, opening new physics potential via *e–p* and *e–A* collisions.

Both detectors, BM@N and MPD, have seen the formation of their respective international experiment collaborations.

JINR PARTICIPATION IN FOREFRONT EXTERNAL EXPERIMENTS OFF-SITE

Furthermore, of strategic importance is the JINR participation in forefront external experiments off-site, like at existing facilities, such as LHC, SPS, RHIC, and at facilities under construction, as for example the international FAIR facility in Germany, or in planning, like the foreseen Electron–Ion Collider (EIC) facility in the USA. However, the key factor must be a mutual benefit from the exchange of data, of new scientific technologies and of theoretical know-how. The JINR strategy for cooperative research at other accelerator centres will be linked closely to the discovery potential of the experiment and of the value to JINR, and also to FAIR and the future of CERN within EU global strategies.

NICA SPIN PHYSICS

Spin Physics was also a key programme at the Synchrophasotron and has been expanded at the Nuclotron. Still as of today, studying of the gluon contribution to the nucleon structure is of fundamental importance as it is needed to understand the nucleon internal structure as a whole. The unpolarized nucleon structure is well known, while our knowledge of polarized parton distributions is limited.

Polarized proton and deuteron beams will be available at NICA, and experiments with them will be possible at the second intersection point of the Collider. The luminosity is expected to be in the range of 10^{30}–10^{32} $cm^{-2} \cdot s^{-1}$. The opportunity to have such high luminosity collisions of polarized protons and deuterons at the NICA collider allows for studies of a great variety of spin and polarization-dependent effects in the hadron–hadron collisions.

The main goal of the proposed experiment is to study the polarized gluon structure of proton and deuteron in the production of charmonium, open charm and direct photons. At its initial stage, the Spin Physics Detector (SPD) is supposed to focus on various unpolarized and spin-dependent effects in interactions of protons, deuterons and light nuclei.

The international SPD collaboration has presented a Conceptual Design of SPD at the NICA collider. Various technical options are under discussion and simulations before finalizing a Technical Design Report at the end of 2021. The plan is that SPD is ready for data taking when NICA collider is operational.

PARTICLE PHYSICS AT THE LHC AND BEYOND

JINR is deeply involved in international Particle Physics, has made important hardware contributions to scientific and technical infrastructures inside and outside JINR, and has been strongly involved in the harvesting of scientific results through participation in data analysis. The JINR overall strategic position in the particle physics programme presented in the report aims to be well integrated into the European and worldwide particle physics strategies and should guarantee JINR playing an important role in this field of Science.

The JINR strategy is based on a balance between home and international experiments. Both must be scientifically solid, well defined, expanding new frontiers in our understanding of physical laws that govern the Universe. The researchers from all the JINR Member States should be able to participate in stimulating research and exploit the potential of the unique JINR infrastructure, which some university groups cannot afford.

The main directions of research for the mid- and long-term periods are related to:

- precision exploration of strongly interacting states, including proton structure, QCD phases, like quark–gluon plasma, new hadronic states, including exotic multi-quark states;
- study of electroweak and flavour physics;
- further insights in understanding the Universe evolution in collider experiments, including the search for dark matter;
- astrophysical and cosmological observations and investigations of gravitational waves, multi-messenger astronomy and dark sectors in non-accelerator experiments;
- experimental and theoretical determination of a model, Beyond the Standard Model (BSM);
- development of accelerator science and technologies.

Many if not all of these directions are interwoven and interconnected. There is a strong synergy between these branches of research, as well as between the expertise of the different laboratories of JINR.

ACCELERATOR-BASED RESEARCH AND FRONTIER ACCELERATOR TECHNOLOGIES

JINR, a more than 25-year-long-standing member of the ALICE, ATLAS and CMS Collaborations at CERN LHC, is one of the major participants with great investments into these projects. The major discoveries of these experiments were the observation of the Higgs boson production and its decay, and the Quark–Gluon Plasma at very high temperatures. From 2023 to 2026, the LHC will be upgraded to a High Luminosity-LHC (HL-LHC). The integrated luminosity by 2038 is expected to be 20 times larger than all currently accumulated statistics, opening the room for further insights and discoveries.

JINR plans to invest further in ATLAS, for upgrade of RPC of the Muon System, upgrade of electronics of liquid Ar electromagnetic LAr EM Calorimeter, Tile Hadronic Calorimeter, TDAQ System and production of the High-Granularity Timing Detector (HGTD). In CMS the investment will concern the upgrade of the endcap muon system, based on precision cathode strip chambers (CSCs), and the construction of the high-granularity hadron calorimeters (HGCALs).

In the long-term period, after the High Luminosity-LHC upgrade, JINR is urged to play a leading role in physics analyses like precision measurements within the SM, searches for BSM physics, including Supersymmetry and exotics, studies of the hadron structure.

The JINR researchers will join different scenarios of pushing the energy and luminosity frontiers even further for the post HL-LHC era and develop the necessary expertise whenever required to play a leading role in these explorations.

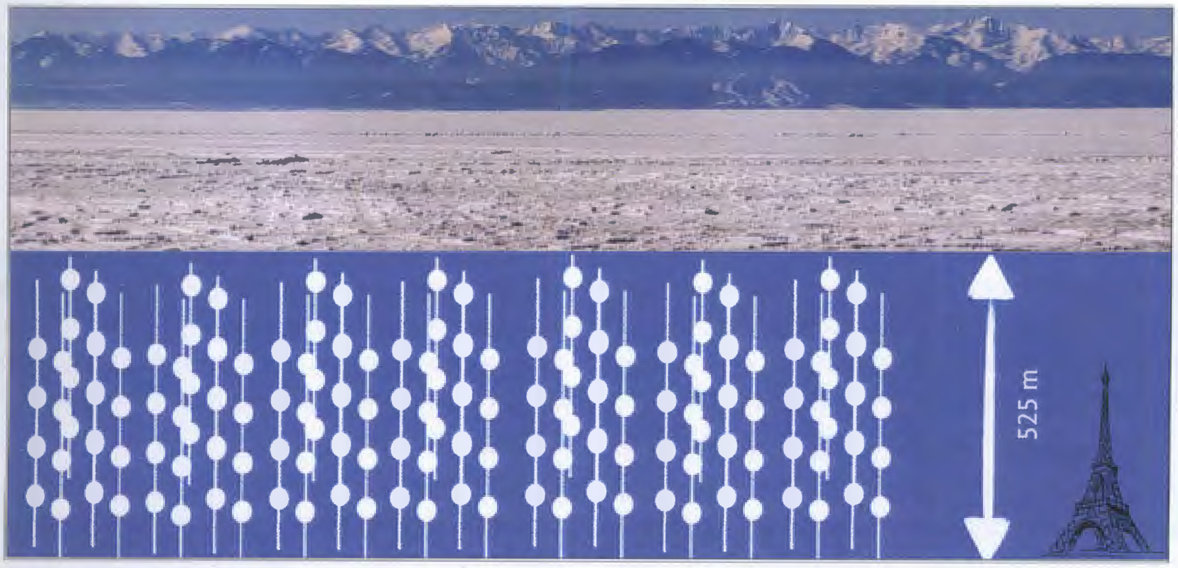
At lower energies, the Dzhelepov Laboratory of Nuclear Problems (DLNP) is involved in the experiments Mu2e, COMET, BES-III and PANDA at FAIR. The Veksler and Baldin Laboratory of High Energy Physics (VBLHEP) is dominantly engaged in the Nuclotron and NICA experiments BM@N, MPD and SPD, but also in the CERN experiments COMPASS-2, NA61, NA62, NA64 at the SPS, or in STAR at RHIC and in FAIR experiments HADES, CBM and PANDA.

Certainly, participation of JINR in these off-site experiments – some ongoing, some under construction – will be evaluated as to scientific benefit and discovery potential, and in view of priorities of JINR. As mentioned before, the key factor must be a mutual benefit from the exchange of data, of new scientific technologies and of theoretical know-how.

NEUTRINO PHYSICS AND ASTROPARTICLE PHYSICS

Neutrino Physics plays a key role in understanding of the laws governing the Universe. Nowadays, the significance of Neutrino Physics is steadily increasing since it has entered its precision era.

JINR, due to the explorations led by B. Pontecorvo since the 1950s, developed a strong and influential neutrino school. JINR leads the world's largest Neutrino Programme covering all sources of neutrinos, strong theoretical investigations and data analysis.



Baikal-GVD (Gigaton Volume Detector)

Together with INR (Moscow), JINR plays a leading role in the construction, data taking, reconstruction, calibration and data analysis of Baikal-GVD (Gigaton Volume Detector) with an aim to build a 0.4 km^3 detector by 2021 and 1.0 km^3 detector by 2027. Today, Baikal-GVD is the largest neutrino telescope in the northern hemisphere with its 0.35 km^3 detector.

JINR intends to strengthen further its leading position by increasing substantially efforts in the data analysis for yielding the highest quality scientific results in observation of ultra-high astrophysical neutrinos and related studies.

The major motivation of JUNO, the reactor antineutrino experiment, is the determination of neutrino mass ordering at 3–4 standard deviations confidence level. JINR is a major JUNO collaborator with substantial scientific and material contribution.

The next breakthrough in the determination of neutrino mass ordering and CP-violation in the lepton sector can be expected from a global analysis of neutrino data and from precision measurements at accelerator long-baseline experiments. JINR, successfully participating in the NOvA experiment, intends joining the DUNE experiment in the United States.

MULTI-MESSENGER ASTRONOMY INCLUDING GRAVITATIONAL WAVE DETECTION

It is understood nowadays that phenomena which occurred in the Universe should be studied by simultaneous observations of different signals. These multi-messengers could give a further insight into the evolution of the Universe.

Baikal-GVD mentioned above is one of the cornerstones of this approach. The TAIGA installation – a set of gamma and muon telescopes hosted in Siberia, in Tunka valley, to the south of Lake Baikal, can be regarded as a supplemental instrument in terms of multi-messenger astronomy. Together, Baikal-GVD and TAIGA can provide a unique multi-messenger observation of the Universe integrated into the global astroparticle network.

The discovery of gravitational waves is one of the most remarkable discoveries ever, which opened a new window to observe the Universe. JINR scientists propose to pursue this direction of research, which requires developing a new expertise in many fields ranging from General Relativity to precision laser interferometry. It is important to note that JINR has already made the first step in this direction, having installed its brand new laser inclinometer at the VIRGO detector. In the mid-term, JINR will develop the presently missing needed expertise and prepare itself for competent collaboration at existing gravitational wave detectors like LIGO or VIRGO, and/or the third-generation detector Einstein.

NEUTRON RESEARCH IN CONDENSED MATTER AND NEUTRON PHYSICS

JINR has a long tradition in Condensed Matter and Neutron Physics research employing neutrons from their on-site research reactors. JINR intends to stay at the forefront of this science by building the best neutron source possible.

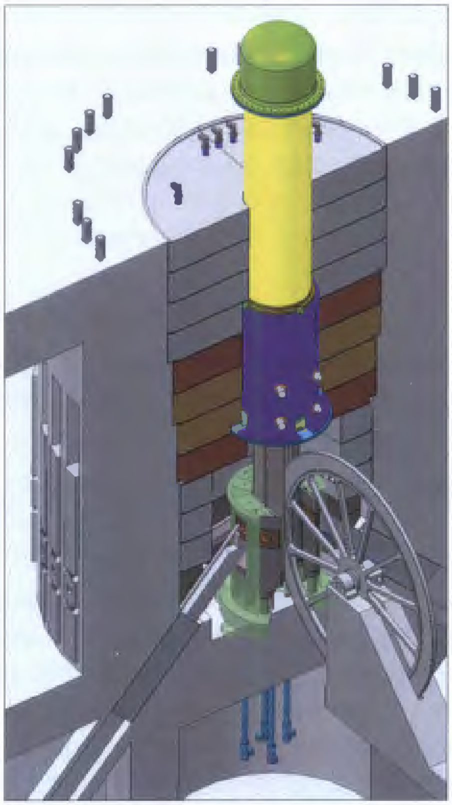
Neutrons are used for studying fundamental symmetries and interactions, structure and properties of nuclei, but nowadays neutrons are mostly required in investigations of condensed matter including solid states, liquids, biological systems, polymers, colloids, chemical reactions, engineering systems, etc. Moreover, extremely low-energy neutrons are also a very promising tool for research in the field of particle physics and studies of fundamental interactions.

Considering the present-day tendency in neutron facility development, after 2030 only five sources will be available including three currently operating facilities: ISIS (Didcot, UK), SINQ (PSI, Villigen, Switzerland), FRM II (TU Munich, FRG), and two new sources – ESS (Lund, Sweden) and steady-state reactor PIK (PNPI NRC KI, Gatchina, Russia), both under construction, with the start of operation planned for 2023–2024.

Thus, the need for a next-generation high-flux neutron source is driven by a growing interest in neutron investigations against the background of a steadily decreasing number of neutron sources in the world, as evidenced by the analysis of a specially established ESFRI Physical Sciences and Engineering Strategy Working Group. Such a new source will to a great extent compensate the losses of the neutron beam time in Europe and attract users that are currently served at ILL and medium-flux reactors in Germany, France and Hungary.

JINR has proposed to build a new advanced neutron source, DNS-IV (Dubna Neutron Source of the 4th generation), on site. In combination with modern moderators, neutron guides and neutron scattering instruments, DNS-IV promises to become one of the best neutron sources in the world and will open unprecedented possibilities for scientists from JINR Member States and worldwide for research in condensed matter physics, fundamental physics, chemistry, novel materials and life science.

DNS-IV will provide shorter neutron pulses, however containing the same number of neutrons as at the European Spallation Source (ESS, to be operational in 2024). Indeed, it will be as good as ESS for low-resolution experiments and significantly outperform it for high-resolution experiments.



Schematic view of IBR-3

From the different concepts studied, a pulsed neutron reactor IBR-3 with Np-237 core was chosen for the DNS-IV project. Therefore, the pulsed neutron reactor IBR-3 with NpN fuel has currently become the working project with a planned start of the DNS-IV operation in 2036–2037.

THEORETICAL PHYSICS

Throughout the JINR history, research in theoretical physics has always been one of the pillars of the JINR scientific programme, which has contributed to many major advances in Science. The Bogoliubov Laboratory of Theoretical Physics (BLTP) is one of the worldwide biggest research centres specialized in theoretical research at the frontiers of fundamental physics. BLTP has an expertise in a wide range of areas related to the theory of fundamental interactions, nuclear theory, condensed matter physics and modern mathematical physics. Studies at BLTP are carried out in close cooperation with scientists from many world's leading research centres and in coordination with the JINR experimental programme.

The scientific and organizational policy of the Laboratory relies on multidisciplinary theoretical studies on the basis of advanced mathematics, support of the JINR experimental programme, strengthening of the scientific brainpower through the interplay of research and education. These principles as well as forming the international scientific task force groups dedicated to the enhanced study of the emergent hot topics will be in focus of a long-range development of theoretical physics at JINR.

BLTP and JINR will stay attractive to the international scientific community by organizing series of topical workshops, conferences, and schools for young scientists. A special emphasis will be placed on active participation of BLTP in educational programmes of JINR as well as on its direct cooperation with universities of the JINR Member States. The unique feature of Dubna International School of Theoretical Physics (DIAS-TH) is its coherent integration into the scientific life of BLTP and JINR, ensuring regular and natural participation of the leading scientists in education and training activities.

THEORY OF FUNDAMENTAL INTERACTIONS

The theory of fundamental interactions of elementary particles based mostly on quantum field theory plays the central role in describing the properties of matter at the microscopic level. In particular, it is forming the solid background of quantitative analysis of both accelerator and non-accelerator experiments involving leptons, hadrons and heavy ions. The JINR long-term research programme in this field of theoretical physics will include a wide range of the most significant topics, running from the high-precision tests of the Standard Model and critical phenomena in hadronic matter to Dark Matter and Dark Energy problems.

Major attention will be paid to phenomenology of the Standard Model, searches for signatures of new physics beyond the Standard Model, neutrino physics, hadron structure and spin physics, heavy flavour physics and hadron spectroscopy, critical phenomena in hot and/or dense rotating hadronic matter in the presence of strong electromagnetic fields, the Dark Matter problem, and astrophysical aspects of elementary particle physics. Theoretical research in the field of particle and relativistic nuclear physics will be focused on the support of physics programmes of major international collaborations with JINR participation (LHC, RHIC, FAIR, etc.), and those at the JINR basic facilities, primarily, of the NICA/MPD and NICA/SPD projects.

NUCLEAR THEORY

The central questions of nuclear physics are: How do the forces between nucleons form bound nuclei? How does the nuclear chart emerge from the underlying interactions? How does the complexity of the bound and continuum nuclear structures arise from the interaction between nucleons? Which role if any at all can the internal quark structure of the nucleons and their color degrees of freedom play in the dynamics of nuclear reactions? To answer these questions, it is necessary to develop a unified theoretical approach to treat few- and many-body systems including a consistent description of nuclear reactions. Such an approach will play an important role in explanation of the experimental data and in guiding the experimental programmes in nuclear structure of exotic nuclei, nuclear dynamics, and nuclear astrophysics. At the same time, nuclear theory will be involved in a variety of interdisciplinary studies in particle, atomic, and statistical physics.

Investigation of the properties of exotic and superheavy nuclei is the goal of the experimental projects DRIBs-III and "The Superheavy Element Factory" at JINR and projects in Europe, the United States, China, and Japan. Parallel to these experiments, microscopic self-consistent nuclear models will be elaborated which include non-harmonic and fragmentation effects beyond the mean-field approximation. The models have to evaluate the rates of various nuclear reactions for astrophysical purposes. Nuclear reactions in stellar environment will be studied with the rigorous methods of the few-body theory as well. In the context of multidisciplinary research, the methods of the few-body theory will be developed in application to ultracold atoms and molecules in confined geometry of laser traps.

THEORY OF CONDENSED MATTER

Research programme will be based on both a systematic development of the general methods of statistical physics and studies in the condensed matter physics tightly correlated with practical problems in the field of nanotechnology for creation of new materials and electronic devices.

Models in condensed matter physics will be studied by using methods of equilibrium and non-equilibrium statistical mechanics with the aim of revealing general properties of many-particle systems based on the ideas of self-similarity and universality. Along with that, theoretical research will be focused on the analysis of systems with strong electronic correlations such as transition metal compounds, high-temperature superconductors, colossal magneto-resistance compounds (manganites), heavy-fermion systems, low-dimensional quantum magnets with strong spin-orbit interaction, topological insulators, etc. Theoretical research at BLTP will go along with the experimental studies of particular materials conducted at the Frank Laboratory of Neutron Physics. Investigations in the field of nanostructures and nanoscaled phenomena will be performed to find physical characteristics of nanomaterials, which are promising for various applications in modern nanotechnologies. The problem of quantum transport in carbon-based and molecular devices, as well as the resonance tunnelling phenomena in various hetero-structures and layered superconductors, is of special interest and will be investigated.

MODERN MATHEMATICAL PHYSICS

Superstring theory, the most serious and worldwide pursued candidate for the unification of all fundamental interactions including quantum gravity, will be one of the central topics in mathematical physics studies at BLTP. This requires a wide range of precise classical and quantum superstring solutions, application of modern mathematical methods to the fundamental problems of supersymmetric gauge theories, development of microscopic description of Black Hole physics, elaboration of cosmological models of the early Universe. In applying and developing new ideas generated with string theory, it is crucial to use mathematical methods of the theory of integrable systems, quantum groups and noncommutative geometry, superfield methods, including the method of harmonic superspaces.

HIGH-PERFORMANCE COMPUTING

Implementation of the outlined research programme in theoretical physics, first of all related to Lattice QCD and, in general, theory of hadronic matter under extreme conditions, multi-loop calculations in the Standard Model, astrophysical and cosmological modelling, will necessarily boost development of high-performance computing infrastructure of JINR to the highest level.

RADIOBIOLOGY AND ASTROBIOLOGY

Heavy charged particles are an excellent tool to address fundamental problems of modern radiation biology and genetics. In contrast to photon radiation, which uniformly deposits energy within the cell nucleus, heavy charged particles densely release energy along their tracks. It results in complex and clustered DNA damage and determines the particles' high biological efficiency. In Space, high-charge and energy (HZE) ions of the Galactic Cosmic Rays (GCR) make a great contribution to the health risk to astronauts during manned deep space missions. Furthermore, hadron beams – protons and carbon ions – are beneficial for radiation cancer treatment, especially for deep-seated tumours, due to their depth-dose distribution with a sharp maximum at the end of the particle range (the Bragg peak). Charged particle tumour therapy and space radiation protection are becoming increasingly urgent fields of modern radiobiological studies.

The radiobiological experiments planned at JINR's accelerators will be aimed at studying the mechanisms of the action of charged particle beams at the molecular, cellular, tissue, and organismal levels of biological organization. Special attention will be focused on applied innovation research, including new ways of increasing the biological effectiveness of radiation therapy with charged particle beams and the analysis of damage to experimental animals' central nervous system in order to estimate the radiation exposure risk to crews on interplanetary flights.

The Laboratory of Radiation Biology (LRB), a strong new member of the recently formed International Biophysics Collaboration, collaborates with many scientific institutions of JINR Members and other countries.

The great advantage of conducting research at LRB is the availability of numerous radiation sources, including heavy-ion beams of different energies. JINR's basic facilities offer an excellent opportunity of modelling the biological action of space radiation. LRB has proposed a novel Nuclotron-based technique of modelling of radiation fields with continuous particle energy spectra generated by GCR inside spacecraft in deep space.

Another major advantage is an excellent opportunity to perform large-scale *in vivo* animal exposures in collaboration with leading experts in this field – first of all, with RAS Institute of Biomedical Problems. The worldwide unique experiments on primates for the estimation of radiation risks of CNS (central nervous system) disorders and carcinogenesis are in progress at LRB. Application of modern omics technologies (genomics, transcriptomics, proteomics, metabolomics) to the analysis of radiation-induced disorders of CNS is foreseen.

Development of various approaches to increase tumour radiosensitivity by interfering with the action of biochemical regulatory networks of the cell is in progress at LRB. For this purpose, the application of pharmaceuticals, transgene systems and methods of their targeted delivery will be performed. A new method of the enhancement of low-LET (linear energy transfer) ionizing radiation's biological effectiveness by the transformation of non-lethal DNA damage to lethal has been invented and recently patented by LRB. The method has been tested *in vivo* and *in vitro*, which makes it very promising for radiation medicine.

LRB develops the hierarchy of mathematical models to simulate radiation-induced pathologies at different organization levels and time scales. In addition to the traditional Monte Carlo technique, LRB's approach involves computational methods from different knowledge areas (molecular dynamics and simulation of brain neural networks). The computation of radiation damage to the CNS structures was initiated and is continued by NASA and LRB.

Astrobiology studies life in the broadest sense: its origin, evolution, and presence in the Universe. To answer the question of the exogenous origin of life, the early stages of transition "from the inanimate to life" can be reproduced in ground experiments using particle beams as an energy source. For the first time, the synthesis of prebiotic compounds in the "formamide + catalysts" system under exposure to particle beams has been performed in collaboration with Italian universities within the framework of research on the Panspermia hypothesis.

The key to the successful fulfilment of the 2030 Programme is the possibility to conduct radiobiological research at the Nuclotron (VBLHEP). A special irradiation station with scanning pencil beam, proper beam optics, monitoring and specialized experimental target area will be installed for irradiation of molecular samples and cell cultures, as well as rodents and primates.

INFORMATION TECHNOLOGY

The mission of the Laboratory of Information Technologies (LIT), is two-fold:

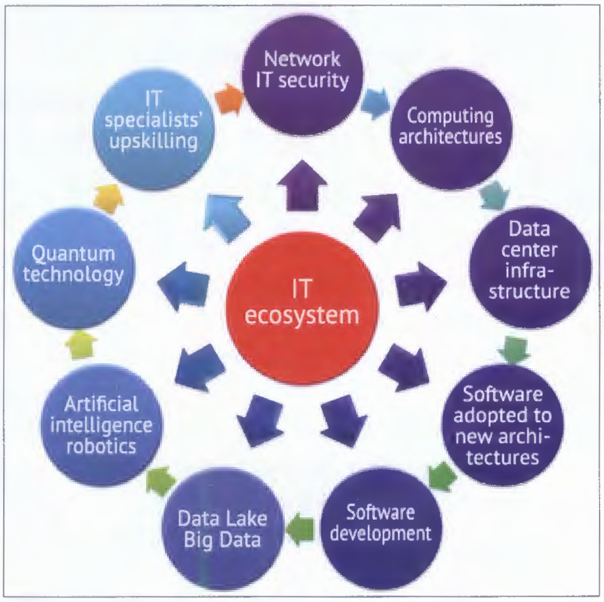
- to serve the scientists of JINR and its Member States in the pursuit of their research projects by developing Methods, Algorithms and Software for Modelling Physical Systems, Mathematical Processing and Analysis of Experimental Data;
- to assure that the IT infrastructure and IT know-how of JINR experts are always of latest state of the art as to performance and energy efficiency.

Presently, the JINR IT infrastructure has been developed in close connection with CERN and other Institutes of Nuclear and High-Energy Physics. JINR is a strong part in the Worldwide LHC Computing Grid (WLCG), which represents a geographically distributed computing environment for processing and storing experimental data of all the LHC experiments, and supports other large-scale experiments not only in particle physics. It is capable of managing hundreds of petabytes of data, providing access to the entire community to computing resources and data storage systems and integrating national and international structures.

The original concept of grid has been changed to a complex, heterogeneous computing system that combines computing resources of various concepts: HTC (High Throughput Computing), HPC (High Performance Computing), Volunteer computing, commercial and non-commercial cloud computing.

The JINR research programme for the next decades is aimed at conducting ambitious and large-scale experiments on the Institute's basic facilities and in the framework of worldwide cooperation. The programme is connected with the implementation of the NICA megaproject, the construction of new experimental facilities, the JINR neutrino programme, the upgrade of the LHC experimental facilities and the programmes on condensed matter physics and nuclear physics. The implementation of the projects mentioned above entails adequate and commensurable investments in the systems providing the processing and storage of increasing data volumes. In this regard, the further development and performance extension of the JINR Multifunctional Information and Computing Complex (MICC), as well as the provision of novel IT solutions to the Complex users and the increase in its operation efficiency, are the uppermost tasks of LIT.

The JINR computing infrastructure consists of numerous computing components and IT technologies to solve JINR tasks, from theoretical studies to experimental data processing, storage and analysis. The JINR MICC is the key element of this infrastructure and plays a defining role in research, which requires modern computing power and data storage systems. It encompasses the IT ecosystem for the NICA project, Tier-1 of the CMS experiment at JINR, Tier-2/CICC providing support to the experiments at the LHC, FAIR and other large-scale experiments, as well as support to users of the JINR Laboratories and its Member States;



IT ecosystem

the integrated cloud environment of the JINR Member States for support of JINR users and experiments (NICA, BES-III, NOvA, Daya Bay, JUNO, etc.); the HybriLIT platform with the "Govorun" supercomputer as a major resource for high-performance computing being a hyper-convergent system built on 100% liquid cooling in the "hot water" mode and having an energy efficiency of less than 1.06. Besides carrying out massively parallel calculations, first of all related to the research programme in theoretical physics, the "Govorun" supercomputer is used for modelling an entire system of computing for all the experiments of the NICA complex. It truly represents a designed future computing solution for any experiment.

LIT plans to establish an IT ecosystem, i.e. a dynamically evolving IT platform, which responds to the rapidly developing IT world. The promising directions of modern information technologies are Artificial Intelligence and Robotics, Machine Learning as well as Quantum Technologies and Big Data Analytics, Machine Learning. The development of the scientific IT ecosystem will depend on novel technologies for acquiring, analysing and sharing data. This system must be very flexible and open to new computing methods such as quantum, cognitive calculations, machine learning methods and data mining, as well as to any developments of new algorithmic bases.

The IT ecosystem will be a basic platform for training IT specialists, able to elaborate algorithmic and software solutions in all fields needed at JINR.

In summary, JINR LIT will further provide forefront service to scientists involved in JINR collaborations, on- and off-site of Dubna, by continuing to develop telecommunication technologies, computing systems, algorithms and software, technologies of data processing and analysis, as well as information security.

DETECTOR TECHNOLOGIES

JINR is internationally recognized for its advancement of detector technologies. However, this expertise must be strengthened further for reaching latest high-tech standards and pushing further the frontiers. Therefore, a considerable amount of knowledge and expertise must be elaborated in modern electronics, robotics and precision mechanics. R&D of gaseous or solid-state sensors/detectors at reactors, cyclotrons, synchrotrons, colliders and in cosmic ray detector installations of largest size will benefit immensely from creation of the centre for the development of advanced detectors. CHIP design and novel detector design will be possible at JINR. With the existing irradiation facilities at JINR it becomes possible to meet the demand of radiation hard detector and electronic system development of all sizes. This centre must have close ties to LIT in order to become leading in modern digital and information approaches.

The close collaboration of JINR with the detector laboratories of GSI and CERN is greatly appreciated. The JINR management will take all the necessary measures to attract to

JINR world-level experts to lead perspective directions within detector technologies, micro-electronics and ASIC chip design, and to provide the means for equipping JINR detector laboratories with state-of-the-art equipment and instrumentation.

INNOVATIONS

The strategic goal of the JINR innovation development for the period up to 2030 is to make the Institute a leading centre for the transfer of knowledge to the JINR Member States in the field of nuclear physics and accelerator technologies.

The implementation of the innovation activity plans involves the concentration of efforts in the following main areas:

1. Applied innovative research at the NICA accelerator complex. The main task is to complete the creation of three specialized research beamline channels with end stations for irradiation of the radiobiology objects (400–800 MeV/nucleon), for testing of radiation hardness of electronic components (3 and 150–350 MeV/nucleon) and for research into nuclear waste transmutation and nuclear data compilation (1–4.5 GeV/nucleon).

2. The establishment of an interlaboratory International Innovation Centre for Nuclear Physics Research, the main tasks of which will be the development of technologies and methods in the field of nuclear and radiation medicine, radiation materials science, corresponding IT as well as advanced training of professionals from JINR Member States in the field of radiation biology and medical physics.

Several new facilities will be built and set in operation in 2021–2026 in the framework of the Innovation Centre programme:

- DC-140 cyclotron for the development of technologies for radiation materials science and applied research with heavy-ion beams, electronic component testing, track pore membrane research and production;
- Superconducting 230 MeV p-cyclotron as a pilot element for future medical center for patient treatment, promotion of new hadron beam therapy methods, e.g., treatment planning, flash-therapy and pencil beam method;
- 40 MeV Rhodotron microtron accelerator coupled with radiochemical laboratory Class-I for development of methods of radioisotope production (^{225}Ac, ^{99m}Tc, etc.) in photonuclear reactions for nuclear medicine.

3. Radiation Biology Initiative: radiation neuroscience and clinical radiobiology. Wide application of omics technologies (genomics, proteomics, metabolomics) and bioinformatics to reveal the mechanisms of neurodegenerative diseases is foreseen. Innovative research in the field of clinical radiobiology will be based on the development of approaches to increase tumor radiosensitivity by interfering with the action of genetic regulatory network of the cell using pharmaceuticals and transgene systems. Methods of targeted delivery (molecular vectors) of radiosensitizers and radiopharmaceuticals will be advanced. Breakthrough technologies of oncological diseases treatment, fundamental and exploratory research in the field of space radiation biology and genomic technologies will be pursued.

Beyond above listed, but activities already on the cruise track: artificial intellect and quantum technologies at LIT and VBLHEP; superconducting energy storage device up to 3MJ; R&D for SC linacs (cw); micropixel avalanche photodiodes, medipix for tomographs, Laser Inclinometer, etc. In that context, medium-term interlaboratory projects are needed to create R&D centres in the interest of the Member States and with their active involvement — LifeScience, EcoEnergy, BigData and Quantum Technologies. Even this does not exhaust the sphere of JINR's innovative interests. We will actively develop carbon-free research and technologies. Of course, JINR will be in the orbit of research related to hydrogen energy: low temperatures, storage, transportation, use of liquefied gases. Expansion of the experimental research agenda — as a place for mastering new technologies and a testing ground for breakthrough scientific research (Open Research Space @ DUBNA).

HUMAN RESOURCES, EDUCATION AND TRAINING PROGRAMMES

The necessity of a well-defined educational programme at JINR is evident and must be continuously adapted to guarantee new highly trained generations of researchers, engineers and technicians. Such a programme will rely on on-site educational and training programmes but will also depend on the strong interaction with universities and training centres in the JINR Member States. Only in close collaboration with these institutions can a sustainable development of JINR and a successful realization of the projects described above be guaranteed. The creation of a higher engineering school in Dubna based on the Dubna State University is of great importance. Proven and/ or new methods of training and recruiting of personnel include:

- supervision of practical, bachelor, master, and PhD works prepared by students belonging to scientific and technical departments of universities from the JINR Member States;
- excursions to the various JINR facilities and lectures about activities of each of the JINR Laboratory for students;
- planning of various supplementary schools for students of local universities during scientific conferences organized by JINR.

Great importance is attached to the educational and training programme for guaranteeing new highly qualified generations of researchers, technicians and engineers, well trained for meeting the challenges of the future. Competing with industry on salaries and benefits, in Russia and abroad, is a challenge.

Moreover, JINR plans to develop a strong, innovative and bright outreach programme meeting the world-class standards of this new field of communication. The outreach service that provides accurate and appealing information to a wide audience is understood nowadays to be inevitable. Furthermore, for the numerous international projects of JINR and their national and international collaborators, special efforts will be made to constantly improve a user-friendly environment on site at JINR.

CONCLUSION

This JINR Strategic Long-Range Plan sees a vigorous determination of this Institute to stay at the forefront of Science in the chosen fields of Basic Research. For that, several new facilities are proposed or under construction, such as:

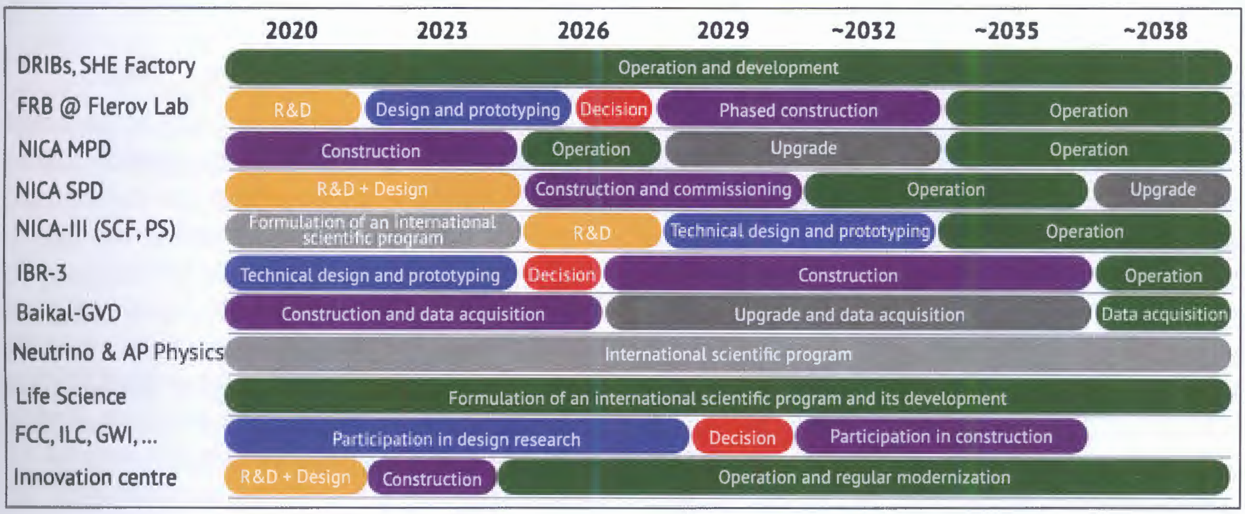
- Superheavy Element Factory;
- NICA facility with its fixed target programme and the collider mode for Heavy-Ion collisions;
- NICA facility for Spin Physics with polarized beams;
- Further development of the NICA facility after 2030–2035 (electron–ion collider, supercritical Coulomb fields, proton source for neutrino physics);
- Neutrino telescope Baikal-GVD and its further development for Multi-Messenger Astronomy, study of fundamental properties of most energetic cosmic neutrinos, indirect search for galactic dark matter and applied research;
- New Pulsed Neutron Source based on a high-intensity pulsed neutron reactor IBR-3 with Np-237 core;
- Irradiation facilities for materials science and radiation biology;
- New Rare Isotope Collider Facility;

- Innovation Centre for Nuclear Physics Research;
- Dynamically growing, supercomputer-based IT platform, which responds to the rapidly developing IT world.

In addition, JINR participation in forefront external experiments, in Physics of Relativistic Heavy-Ion Collisions, Particle Physics and Neutrino Physics will be continued, if the discovery potential of the experiments is high and if JINR researchers can play a leading role. The proposed plan foresees a continuation of participation in experiments at accelerator centres around the world (CERN, BNL, DESY, FAIR, GSI, GANIL) and in Neutrino experiments, recognizing the mutual benefit from the exchange of data, of new scientific technologies and of theoretical know-how. Special recognition is given to the strong collaborations on the detector and accelerator projects of JINR with CERN, GSI, DESY and the future large-scale facilities, international FAIR facility in Germany, BNL and FNAL, GANIL, and some others, benefitting strongly all partner institutes.

Furthermore, the Institute will take all measures for strengthening its expertise in latest technologies in microelectronics, ASIC-chip design and detector R&D, as well as material research and accelerator technologies.

Extended educational and training programmes will assure sustainability of JINR expertise and know-how needed for meeting the scientific and technical challenges of the present Strategic Plan.



Matrix of JINR Key Projects

JINR: ATTRACTIVENESS AND COMPETITIVENESS. THE INSTITUTE MEANS PEOPLE

The Institute's activities in the modern global research agenda are the acquisition of new knowledge of a fundamental nature and the development of technologies and innovations for the sake of the sustainable development of mankind. Enhancing human capital, forming a highly qualified workforce with bright creative abilities, creating an effective system for building up and making full use of the intellectual potential in the interest of the Member States are the main priority of JINR's scientific and technological policy in the near future.

Theoretical physics, nuclear physics, elementary particle physics and astrophysics, condensed matter physics, radiobiology and information technology are the areas where the Institute is traditionally among the world leaders. Maintaining this position by concentrating the main material and intellectual resources on the construction and further development of modern unique experimental facilities at the Institute will allow obtaining world-class fundamental results. The main basic facilities are the NICA complex and its gradual development, the SHE Factory and radioactive beams, the Baikal-GVD telescope as a part of the Global Neutrino Network, a new-generation high-intensity neutron source, and a hyper-converged computing cluster. Performance management on the basis of such a large-scale and multidisciplinary infrastructure is the most important of the Institute's activities, which is necessary for the growth of its attractiveness and competitiveness both in the Member States and in the world scientific community as a whole.

The modern rapidly changing world scientific, technological, and economic order gives rise to new challenges. The existing global trend towards the development of research in the field of life sciences, digital technologies, and clean energy requires the expansion of the medium-term programme of JINR's activities in directions that are new for the Institute.

The Institute should actively be included in the current global research agenda taking into account the expectations and demands of the JINR Member States, including the participation in building research infrastructures in these countries in collaboration with national institutions. The development of the research programme in the areas of fundamental science which are traditional for the Institute, among them in high-risk research, at the request of the Member States will be supplemented by applied and innovative projects, which will strengthen and harmonize the architecture of the Institute's scientific programme.

Effective work in this direction is possible under the condition of constant monitoring and analysis of trends in the development of the priorities of the Member States in the scientific and technological areas and in finding optimal combinations for the Institute in the applied and innovative research of two complementary approaches: diffusion-oriented vs mission-oriented research.

JINR should ensure a high level of accessibility for scientific partners, safety, and a maintenance culture of the research infrastructure.

This scientific policy positions the Institute as an international platform for Open Science, both for the development of breakthrough technologies necessary for the implementation of modern fundamental research, and for the development of new technologies that require serious support from fundamental science. In addition, being a centre of methodological support (Policy Institute) for organizing international collaborations and megascience projects is considered to be another important function of the Institute.

The generation of new knowledge and technologies, interdisciplinarity and an effective reaction of science to the modern demands of society for an organization that claims to world leadership and the role of an agenda moderator in the coming decades are impossible without a strategic stake in improving the human resources development system. The main priority of the JINR Development Strategy, along with the production of new knowledge, should be the formation of a scientific-engineering and scientific-administrative elite for JINR and the research sphere in the Member States. In Dubna, with the participation of JINR, it is necessary to develop a system of training talented schoolchildren, undergraduate, and graduate students based on individual educational trajectories, as well as to create an appropriate attractive international social environment. Universities of the Member States must meet at the Institute a harmonized system for adapting various educational programmes. One of the key performance indicators on the horizon of 2030 should be the appearance in the format of full-time and remote presence in the JINR orbit of new 1500–2000 highly qualified researchers – our contribution to the formation of international intellectual human capital.

A special place in the activities of the Institute is held by JINR's participation in international projects of the highest world-class level implemented on the basis of other research centres. At the same time, in order to achieve a prevailing balance between "internal" and "external" projects towards the former, a rigorous and competitive assessment of JINR's participation in "external" projects will be carried out based on objective criteria, including the following factors: importance of the successful project implementation for global science; JINR's role in proposing an idea and organizing an experiment ("born in Dubna"); acquisition of new competencies and technologies necessary for the preparation and implementation of projects at JINR; participation of partners on a reciprocal basis in the implementation of JINR projects.

For the successful organization of work on strategic tasks, it is necessary to regularly assess the efficiency and potential of JINR through qualified analysis by the professional community of the Institute and expertise by specially established international committees. This work should be carried out taking into account international best practices reflected in such strategic initiatives as the European Strategy for Particle Physics, the European Strategy for Nuclear Physics & NuPECC Long Range Plan, the Particle Physics Community Planning Exercise (Snowmass) and based on the analysis of key elements of the activity. Evaluation criteria are the presence of research programmes and projects that have no analogues in the world or have analogues in the leading world centres, subject to their deep complementarity; participation of JINR staff in world-class experiments outside JINR with positions of "reference authors" and a significant contribution to the scientific programme; JINR's participation in the world-class collaborations without a definitive investment of resources but with a high proportion of authors of publications and reports presented on behalf of these collaborations by the JINR staff; possibility of developing the basic facilities of JINR and the so-called mirror laboratories in the Member States; competitiveness and attractiveness of the remuneration system; dynamics of the professional growth of a researcher at JINR; attractiveness of the social environment at JINR and in Dubna.

The sustainable development of the Institute is impossible without expanding the geography of the Member States and improving the legal model of an international intergovernmental organization in the context of world geopolitical processes, a new technological order, and an emerging international system of "labour" division in the field of science and technology. JINR is playing an important role in the world arena as a major link in the coordination and development of scientific research, and this role should grow. On the other hand, the Institute is an effective tool for expanding the international partner network of the Member States in a wide range of scientific fields around the world. The ambitious research agenda, the competitive unique niche, the international status, and its location allow JINR to create an appropriate model, being integrated into the global scientific landscape and, along with such centres as CERN, one of the global poles of attraction of intelligence in the international research space.

ORGANIZATION OF SCIENCE AND RESEARCH

The successful implementation of the scientific research programme presented in the JINR Development Strategy requires modernization of the approaches in the organization of science and research activities of the Institute as a key factor that ultimately sets all other principles of JINR's functioning, including personnel and financial policy, administrative and economic activities, international cooperation, etc. The document defining the organizational basis for the effective scientific activity at JINR is the annually updated Topical Plan (TP) for Research and International Cooperation. The Topical Plan must be balanced and provided with the financial and human resources available to the Institute. Regular scientific and resource analysis of the implementation of the TP should be ensured by the organization of independent expertise and effective synchronization of the work of the JINR Science and Technology Councils, of the international Programme Advisory Committees and other specialized committees, as well as of the commissions for the analysis of project implementation, and of the JINR Scientific Council.

The expansion of the Institute's research programme, the increased dynamics of the emergence of new scientific directions, increased competition for leadership in the formation of the global research agenda as well as a significant increase in international staff mobility, require adjusting correction of the structure of the TP and the procedures associated with its filling and implementation. The TP should be based on the concepts of "theme", "project" and "collaboration":

- theme: scientific direction, large infrastructure project, development, and operation of a basic facility. It is possible to open a theme for an indefinitely long period, subject to mandatory reporting and implementation analysis;
- project: scientific, research, technical and other activities of JINR that have a certain time frame and resources (human, material, financial);
- collaboration: scientific activity carried out by a consortium of several research centres that make a significant contribution to the material, financial and HR support of this activity.

The principle of regular analysis of the performance of the leaders of the theme/project/collaboration and updating the administrative structure for supporting scientific themes and areas is a necessary tool, including their intellectual expansion. The Institute should demonstrate the ability of diversification and inclusion when it comes to international standards of scientific and organizational activities.

The organization of JINR's scientific activities is aimed at effectively solving the problems facing the Institute and includes:

- identification of promising projects including high-risk ones, assessment of their scientific significance;
- planning of the necessary financial, material, human and other resources;
- analysis of the quality of scientific results of projects as well as capitalization of costs and contribution to the increase in fixed assets, publication activity, involvement of students, graduate students and young scientists (engineers) in the project, receipt of academic degrees and titles by the project participants, international recognition;
- monitoring of the implementation and timely completion of projects;

– stimulation of the professional and career growth of scientific, engineering and technical personnel, scientific and administrative personnel of JINR, development of scientific schools and the institute of mentoring, ensuring a smooth change of generations with effective and careful consideration of the accumulated competencies and experience.

The organization of scientific activities of the Institute is based on the following principles:

– transition to a flexible system of administration of scientific activities, taking into account the human, financial and infrastructural resources based on the concepts of "theme", "project" (including interlaboratory activities), and "collaboration";
– strengthening of the role of the project as a basic element of the TP. Increasing the independence of projects in terms of personnel and research funding, while increasing the responsibility of project managers for the result;
– development of administrative and managerial tools for the implementation of the activities of international collaborations on the basis of JINR;
– improvement of the system of international expertise of projects and their results, in order to increase its independence and objectivity;
– coordination of the scientific activities of the Institute with long-term plans for the development of science, technology, and higher education in the Member States of the Institute;
– synchronization of the cooperation programmes of the Plenipotentiaries of the Member States with the JINR TP and the Institute's Development Plan, consolidation of funds on the main priorities and tasks;
– maximum use of the potential of existing basic facilities, their integration into the global research infrastructure, participation in the development and use of research facilities of the JINR Member States;
– providing of access for the Member States to the information and computing power of the Institute, as well as to JINR's experimental data and developed technologies;
– elaboration at JINR of a field of innovative and interdisciplinary developments as well as the organization of their implementation in the Member States.

SUSTAINABLE DEVELOPMENT OF JINR AS AN INTERNATIONAL INTERGOVERNMENTAL ORGANIZATION

The current stage in the development of international science and technology cooperation (ISTC) is associated with two complementary processes. There is a rapid transition of the world scientific and technological complex to a qualitatively new stage, characterized by the formation of a global institutional and material infrastructure for research and development, international scientific and technological collaborations as well as a qualitative strengthening of the role of digital and information technologies. The increase in research and development costs, the growth of their complexity, inter- and multidisciplinarity, and the orientation of the world scientific and technological agenda to addressing newly emerging challenges lead to the need to strengthen cooperation between participants in global scientific and technological processes. The revitalization of ISTC is also due to the growth of the mobility of scientific personnel, the increased global availability of research and development results, the emergence of new network forms and partnerships in the field of scientific, technological and innovative interaction.

This general growth in scale and a change in the quality of ISTC are taking place against the background of the rapid formation of new global and regional centres of socio-economic, scientific, and technological development, which increases the level of competition between various centres for intellectual capital and has a profound effect on the nature of international cooperation in the field of science and technology.

Under these conditions, JINR will play a proactive integrating role in global scientific and technological cooperation as one of the world's largest international intergovernmental scientific organizations in terms of the scale of ongoing research, accumulated intellectual capital, and financial resources.

The successful performance of this role is associated with the solution of the task of strengthening JINR as an international intergovernmental organization.

The sustainability of JINR is determined by the following interdependent and complementary directions of the Institute's activities as an international intergovernmental scientific organization:

- ensuring a stable international legal framework for the organization and its organizational basis, namely, the community of the Member States and associated countries, as well as other partners within the JINR orbit;
- ensuring world standards for the organization of highly productive advanced research in the interests of JINR Member States, implemented by the Institute in accordance with its Charter and fundamental principles of international scientific and technical cooperation, such as equality, voluntariness, openness, responsibility, mutual benefit and apoliticism, humanism and commitment to peaceful goals.

Strengthening the community of the Member States should be executed through targeted scientific and technical, HR, administrative and social policy of the Institute, the full international character of which should be provided through interaction with the Member States of the Institute to ensure their interests in the scientific and technical spheres core to JINR's research, as well as timely updating and systematization of the legal framework regulating the Institute's activities, application of advanced international HR, administrative and managerial standards, equally guaranteeing to citizens of all Member States the most comfortable working and social environment at JINR. The work should be based on an individual approach to the relationship of the Institute with each Member State, taking into account the specifics of the national priorities and capabilities of each Member State in the field of research. Interaction with the Member States should also be aimed at intensifying the involvement of their representatives in direct management of JINR, in the process of determining its scientific policy and strategic development.

Within the general complex of relations with JINR Member States, special attention should be paid to interaction with the Russian Federation and its federal organizations, as the hosting country of JINR.

It is strategically important for the Institute to formalize a mutually beneficial format of associated membership as a flexible tool for accession of partner countries to JINR, including the creation of prerequisites for the transition of associated countries to full membership.

For optimal diversification of formats applied in the Institute's interaction with partner countries, it is proposed to develop and implement the status of JINR observer in relation both to countries and to international organizations and associations.

In addition, ensuring the sustainability of the Institute as an international intergovernmental organization will presume activities in such areas as:

- attraction of research organizations of technologically advanced countries to join scientific collaborations of JINR, formalization of their relations with JINR within the framework of agreements at governmental level on joining JINR major scientific and infrastructure projects, as well as international training programmes, as fully fledged partners, and subsequently on association of the corresponding country with JINR with the prospect of full membership;
- creation of prerequisites for the emergence of new international scientific projects and areas of scientific interaction with organizations of non-members of JINR;
- systemized interaction with international intergovernmental and non-governmental organizations/associations/unions, facilitating international cooperation in science and education and implementing programmes in research, science expertise and education, participation in advisory bodies of these organizations and their partner networks; implementation of joint scientific programmes, cooperation plans, and events.

An instrumental role in ensuring sustainable development of JINR will be played by such activities as:

- organization of JINR representations in the Member States;
- development of a network of JINR information centres in research, scientific and educational organizations of the Member States, associated states and other countries;
- communication of JINR research achievements and strengthening of its international image through implementation of targeted PR, advertising and media policies.

JINR Member States; to optimize the personnel training system by transferring the associated infrastructure and labour load to organizations participating in JINR research; ensuring the natural mobility of personnel and, thus, creating prerequisites for the personnel strengthening of both the Institute and the research and scientific-educational organizations in the JINR Member States;

- development of international education and training programmes for scientists, specialists, and management personnel of the Member States;
- development of joint educational programmes as a basis for cooperation between higher educational institutions and JINR in training highly qualified personnel, integration into the higher education systems of the JINR Member States and the European Higher Education Area. Implementation and development of a mentoring approach;
- use of the JINR information centres network in scientific and scientific-educational organizations to initiate personnel mobility and its specialized training;
- development of a system for monitoring the status of the Institute's personnel and analyzing the effectiveness of the Institute's personnel policy.

JOINT INSTITUTE FOR NUCLEAR RESEARCH 1956

SOCIAL ENVIRONMENT: ATTRACTIVENESS, MUTUAL RESPONSIBILITY, OPENNESS

An open, comfortable and attractive social environment is a fundamental element of the ecosystem of the international scientific centre in Dubna. "JINR is our common home on the Volga banks", where favorable conditions should be created for the Institute to optimally implement its international mission, its research and integration tasks, and to maintain the authority of JINR as a leading international scientific platform for the successful professional activities of talented motivated people.

Significant components of a convenient social environment for the staff of the Institute include decent and safe working conditions, a safe, ecologically friendly and comfortable urban environment, access to the most modern services and the organization of educational leisure, an attractive socio-cultural space, a modern and pragmatically organized ecosystem of the working space, opportunities for optimal linguistic, social, socio-cultural, and professional integration.

The further development of the international social environment of JINR should be built on the principles of realizing the highest value of human capital, careful (rational) preservation of the environment, development and augmentation of the infrastructure, as well as the relationship of Dubna with the host region and the capital of the host country, with foreign cities and countries.

It is necessary to use and develop all the competitive advantages of the modern JINR and the town of Dubna:

- JINR's unique scientific and educational potential is a springboard for a successful international scientific career; the ideology of the Institute is focused on supporting and maximizing the potential of its employees;
- Dubna as a comfortable and ecological friendly space for scientific activities and accommodation of staff and their families: a unique (not only for host country) multicultural space that unites creative intellectual potential, like-minded people who are passionate about science; walking distance to a modern cultural, sports, social and educational infrastructure; safety of a personal, creative and social space.

One of the directions for the development of the social environment at JINR is the strengthening of the unifying culture "Institute – Personnel". For the successful implementation of ambitious scientific tasks, it is important that employees should realize the advantages of being involved in JINR, their contributions to its activities, and success. On the other hand, the Institute should also be guided by the principles of creating the most favorable conditions for unlocking the potential of its personnel as well as openness and transparency of internal scientific, organizational and administrative processes.

Implementation of the slogan "JINR is our common home on the Volga banks" implies the formation of a space attractive to all representatives of the JINR Member States, including language, navigation, social issues, free orientation in administrative procedures, and various activities. The most important element of such a space should be respected for the environment, including energy and nature conservation, development and use of the results of carbon-free research and technologies (implying the transition to carbon-free production, equipment, etc.), as well as the use of JINR's developments and participation in relevant international initiatives.

Development of a multicultural social environment, which is a competitive advantage of JINR and Dubna, is possible only through joint support with the town and the Moscow Region of relevant initiatives in the educational sphere, including higher, secondary, and preschool education with the active expert and organizational contributions of JINR.

An important, if not key parameter of a productive social environment is a positive image of the Institute not only as an attractive employer but also as an international Institute for Development. For this, it is important to form the brand of the Institute, reflecting its international status, its brilliant science, success stories, and aspiration for the future. Activities to communicate science are of decisive importance for the development of such an environment, including the establishment of online laboratories and internships, virtual and augmented reality technologies to get acquainted with the research base, promotion of scientific tourism programmes, building professional productive interaction with the media of all available formats, support for initiatives at the intersection of culture, diplomacy and science, the creation of modern exhibition spaces, career guidance and dialogue between science and society, and everything that will ensure international understanding of the goals and meaning of the Institute's activities for its founders and civil society of the Member States.

In the interests of sustainable development of the social environment in a broad sense, it is important to work with personnel and outstanding personalities who have been and are in the JINR orbit. In particular, by preparing various alumni-programmes for former employees, graduate students and visiting professors, members of scientific committees and councils.

SUPPORTING ADMINISTRATIVE ACTIVITIES

The operation of the administrative system of the Institute should be aimed, first of all, at ensuring optimal working conditions for scientific staff and research engineers for the implementation of the tasks formulated in the JINR TP.

The administrative system of the Institute must comply with relevant international standards and support its international nature. The strategic goal of the development of services is to organize their work on the principle of "one-stop shop" with the assistance of a common moderator. Key performance indicators should be the minimization of the required initial data from the applicant, the speed of processing requests, strict adherence to the work schedule, the absence of barriers (including language barriers) in the communication of employees with service representatives, and the safety of working processes. The presence of representatives of the Member States in the administrative services promotes the implementation of useful administrative techniques and successful practices that are common among similar structures of the Member States of the Institute.

In today's rapidly changing world, there is a need for the ability of services to respond in a timely manner and adapt methods of work to current tasks. The exchange of successful corporate practices and methods of administrative services with the offices of Plenipotentiaries and/or relevant ministries/agencies of the Member States, and the regular professional development of employees in the relevant profile contribute to an increase in the level of efficiency of the management structures.

Improving the administrative management system to increase its efficiency requires rationalizing management activities in order to build an optimal organizational structure and develop an effective model of interaction between administrative and management structures (including functional matrices). This includes a competitive procedure for the election of heads of administrative services, their rotation, and regular reporting at the JINR Science and Technology Council as well as the development and use of digital platforms for managing administrative and scientific-organizational processes.

Digital transformation of management processes implies the integration of digital technologies into all aspects of management activities and the replacement of traditional processes of interaction with digital services. The use of modern technologies makes it possible to reduce the time for making managerial decisions by standardizing routine approval processes, eliminating a number of intermediate stages, monitoring and controlling the execution of decisions, and allows taking into account the opinion and needs of the Institute's staff. An indispensable element of successful digitalization is the elimination of paper media duplicating digital information for internal use and strict adherence to the regulations both in time and in the volume of initiator's involvement. Minimizing the number of documents and time without sacrificing functionality is a natural consequence of digitalization, and it should be promoted.

The introduction of digital technologies, the establishment of a unified information system of the Institute, and the development of modern financial and legal services require the use of advanced computing technologies, Big Data analytics, and machine learning. Such systems will allow flexible management of control over access to information, personalized communication of employees with administrative and management structures, feedback and control over compliance with regulations. The development and improvement of a personnel feedback system is an important mechanism for the prompt solution of emerging problems and one of the tools for creating a comfortable working environment.

INDICATORS AND MONITORING OF THE STRATEGY'S IMPLEMENTATION

The Strategy sets the coordinate system and principles for the formation of the JINR Development Programme.

Achievement of the goals, objectives and indicators of the Programme should contribute to the main indicators of the scientific significance and effectiveness of both leading research projects and the Institute as a whole, strengthen and expand the participation of countries, increase the visibility and value of the Institute for society; stimulate the influx to the Institute of highly qualified researchers and specialists with bright creative abilities.

The principles of the organization and target indicators of the efficiency of the administrative management of the Institute should ensure that the scientific, educational, and innovative activities of JINR comply with the most modern international standards.

The system of top-level indicators, aimed at monitoring the implementation of the Strategic Plan for the Long-Term Development of the Institute, consists of two main groups of characteristics. The first group reflects the level of the Institute's ability to perceive, accumulate and increase scientific knowledge, develop research infrastructure, including the virtual infrastructure, strengthen the status of an intergovernmental organization and expand the Institute's international partner network (capacity). The second group characterizes the current performance in the main areas of the Institute's activities: the production of knowledge, technologies, research infrastructure, highly qualified personnel for the JINR Member States and partners, the intensity of the exchange of scientific and technical information demanded by the JINR Member States (out-turn, or productivity).

Each of these two groups of characteristics (capacity vs out-turn) contains indicators of three main types related to research, and research infrastructure, indicators of the Institute as an international organization, human resources and the current state of staff. For each type, the following top-level metrics will be used.

Research capacity:

- science intensity (research, qualifications, technology – actual outstanding achievements, cumulative result);
- uniqueness of research, relevance of the research programme of the Institute in the world scientific agenda;
- total amount of information and data used (Big Data): storage and access to data, analysis, and processing of information;
- capital-labour ratio, age of equipment, efficiency of using infrastructures.

Outstanding research and facilities:

- specific performance indicators for publications, dissertations, patents, and R&D (per researcher per year);
- efficiency of "research time" – cost of resources for research activities (or for the result of research activities);
- index of digitalization and availability of research infrastructures.

JINR as an international intergovernmental organization:

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- position and role of the Institute in the world system of international intergovernmental scientific organizations;
- Member States;
- structure and dynamics of the partner network: associate members, observers, partner organizations, collaborations;
- dynamics of the JINR budget.

Effectiveness of JINR international science and technology cooperation:
- comprehensive indicator of the contribution of the JINR research infrastructures to the search for answers to the global challenges facing the Member States;
- current level of the international science and technology cooperation: users, partners, short-term work visits.

Human capacity:
- sustainability of reproduction and attraction of HR;
- personnel qualification level;
- outstanding scientific leaders.

The current state of personnel – indicators to be monitored:
- structure and dynamics of the number of personnel by categories of employees, qualifications, type of contract, citizenship, age;
- size and structure of salaries;
- staff mobility; dynamics of professional and career growth.

Monitoring and analysis of the top-level indicators are provided by a detailed system of characteristics, parameters, and indicators of the lower levels which will be approved while adopting the next seven-year JINR Development Plan and further annually adjusted.

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