JOINT
INSTITUTE FOR
NUCLEAR
RESEARCH

SEVEN-YEAR PLAN FOR THE DEVELOPMENT OF JINR 2017—2023

WITH AMENDMENTS APPROVED BY THE COMMITTEE OF PLENIPOTENTIARIES OF THE GOVERNMENTS OF THE JINR MEMBER STATES AT ITS SESSION HELD ON 25 MARCH 2021

Dubna 2021

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(Seven-year plan for the development of JINR for 2017–2023 in original edition approved by the Committee of Plenipotentiaries of the Governments of the JINR Member States at its session held on 21–22 November 2016)

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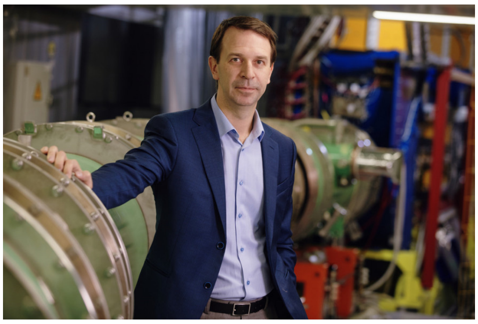
Preface



During the implementation of the current seven-year plan, the execution of the assigned tasks was carried out on the basis of the annually generated Topical Plan for JINR Research and International Cooperation, controlled by internal and external international committees, advisory and governing bodies of the Institute, which took timely decisions on corrective actions when there were circumstances not provided for in the work schedules.

The rapid development of technologies for creating modern physical installations and hardware, increasing demands for competitiveness and attractiveness of new experimental installations for users formed prerequisites for changing the parameters of ongoing projects in order to achieve higher quality of the objects of research infrastructure being put into operation. Risks associated with premature obsolescence of the existing equipment were promptly compensated by planned and unscheduled replacement of the relevant components, determining the addition to the JINR Topical Plan of projects to modernize and expand the capabilities of the existing research infrastructure, as well as a change in the funding profile of some directions.

In November 2020, at a meeting of the Committee of Plenipotentiaries of the JINR Member States, a long-term development strategy of JINR until 2030 and beyond was presented. The available scientific and technical potential of JINR and its visibility at the worldwide scientific arena made it possible to formulate the JINR long-term development strategic plan, declaring the mission of JINR in the context of the globalization of science, the tasks of further increasing the attractiveness of the Institute in response to competition for highly qualified scientific and engineering personnel, as well as approaches to ensuring sustainable development of JINR as an international intergovernmental organization, principles of scientific, organizational and administrative activities, personnel policy and improvement of the social environment.

At the outset of the implementation of the JINR long-term development strategy, objective circumstances arose that motivated the leadership of JINR to conduct a thorough analysis of the fulfillment of the tasks laid down in the seven-year plan. The analysis showed that the pace of actual performance of work on key JINR projects was generally in line with the earlier plans. At the same time, based on the actual and financial performance of the tasks faced by JINR in 2017–2020, in some areas it seems important to bring the content of the seven-year plan in line with the actual deadlines for the work and the available financial resources. Against the background of the intensive development of new scientific directions at JINR, a concomitant task of adjusting the seven-year plan is to consolidate the material and intellectual resources of JINR on the priorities of the current seven-year period.

I am convinced that the measures taken to timely adjust the current seven-year plan will be the key to the successful development of JINR in the coming years and a necessary groundwork for the implementation of the outlined strategic goals.

Grigory Trubnikov
Director of JINR

Preface to the original edition of the seven-year plan

The present Seven-year plan for the development of the Joint Institute for Nuclear Research for 2017–2023, after intensive preparatory work and discussions for two years at the meetings of the Programme Advisory Committees and the Scientific Council of JINR, has eventually been approved by the Committee of Plenipotentiaries of the JINR Member States at its session held in Krakow, Republic of Poland, on 21–22 November 2016.

Taking into account the scope of its ambitious tasks and projects, which assumes the corresponding high level of international cooperation and integration into the global and first of all the European research programmes, I may say that JINR enters into a new era of its development.

JINR is unique for its time-tested trinity of multidisciplinary basic research, international cooperation, and interplay of research and education.

The research programme of JINR includes elementary particle physics, relativistic heavy-ion physics, advanced physics of superheavy elements and exotic neutron-rich nuclei, precision nuclear spectroscopy, neutrino physics and astrophysics, information technologies and computing, fundamental neutron studies, condensed matter physics and new materials, theoretical and mathematical physics, development of modern equipment and experimental techniques, biophysics and radiobiology. Since the establishment of JINR in 1956, scientists from Europe as well as from Asia, Africa and Latin America have been involved in its activities, which has played an important role in determining the scope and versatility of JINR's science policy.

The rich traditions of the Institute and its highly qualified personnel make it possible to share the knowledge with younger generations of scientists and engineers. This also guarantees the high potential of fundamental physics research as well as applied science and innovative activities. JINR keeps being attractive for young researchers of different nationalities.

The experience of the past years accumulated by JINR and the modern trends of the world science indicate that the strategy of the development of this centre will be aimed at:

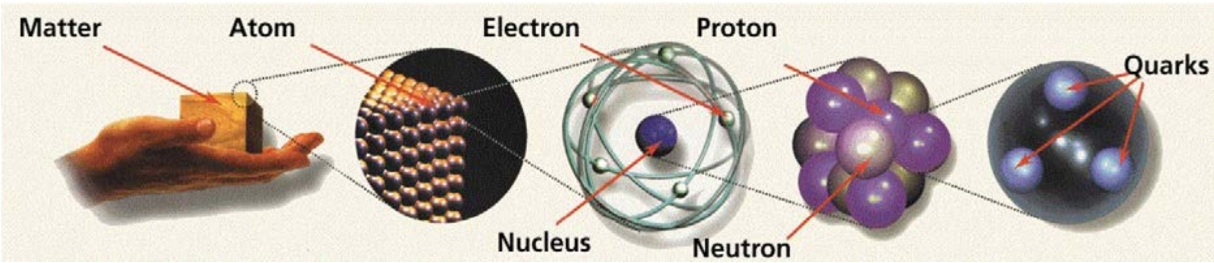
- realizing new world-class projects at frontiers of modern physics on the basis of high professional standards and traditions;
- extending international cooperation around the JINR basic facilities, further integration of these facilities into the European and worldwide research infrastructures;
- attracting new countries to the JINR family;
- maintaining the general infrastructure and “modus operandi” of JINR at the best internationally recognized level.

In conclusion, I would like to express my confidence that the future development of JINR in accordance with the goals outlined in the present Seven-year plan will further demonstrate convincingly to the world the attractive force of scientific knowledge and the unprecedented strength of the ties that unite the scientific community despite the diversity of nationalities, religions and races.

Victor Matveev
Scientific Leader of JINR

Introduction

To substantiate the main goals of the Seven-year plan it is worth having a brief look at the development of modern particle physics, nuclear physics, astrophysics, and condensed matter physics. These areas of research are the core of the JINR scientific programme. Being the most fundamental, they provide the basis and methodology of all science that investigates the structure and properties of matter — from nucleons and nuclei to molecules and condensed matter.



The strategic goal of modern particle physics and astrophysics is the formation of a new unified physical view of the World without "famous problems" of the Standard Model, despite the fact that the latter is an outstanding achievement of humankind. This claim has become very solid after the discovery of the Higgs boson and precise Standard Model descriptions of the numerous data at the electroweak scale of the LHC.

The Standard Model is not the final self-consistent fundamental theory. It can be seen as a low-energy limit of some underlining fundamental theory that would work at a broader energy range up to the Planck scale (10^{19} GeV). The search for this fundamental theory and its experimental verification is a main trend of modern physics. Another, in a certain sense, opposite trend relates to the fact that QCD has yet to explain the quark confinement and other collective phenomena characteristic for strong interactions at intermediate and large distances. The collective behaviour of hadrons is relevant to a whole hierarchy of basic phenomena ranging from colorless hadron (mesons, baryons, glueballs) formation to nuclear reactions and the physics of nuclei, heavy and superheavy nuclei in particular.

Towards a new theory of elementary particles (a new physical picture of the World), the following sources of information are considered most crucial nowadays:

- **Direct search for New Physics at the Large Hadron Collider** (supersymmetry, decays of the Higgs boson, extra dimensions, new types of a state of matter, new particles and interactions, etc.);
- **Neutrino physics and astrophysics** (as the most intriguing and rapidly developing field of modern particle physics);
- Cosmology. Explanation of the nature of **Dark Matter** and **Dark Energy;**
- **Indirect search for New Physics** mainly by means of precision studies of very rare transformations of hadrons and leptons with violation of (flavor) symmetry of generations.

Not being directly connected with New Physics, the **Hadron Structure** is still a very important and unique source for understanding Quantum Chromodynamics (QCD).

In this regard, the first task of the new phase of LHC experiments is to carry out a comprehensive study of the properties of the Higgs boson for convincing evidence of its Standard Model membership. The second task is to get an answer to the question of the existence (or absence) of New Physics at the TeV scale of energies; a special interest is related to the experimental justification of supersymmetry.

Besides the above tasks, the central problem in particle physics today is the nature of neutrinos i.e. those fundamental properties of neutrinos that determine the specificity of their interactions.

Another fundamental puzzle of Nature is addressing the genesis of the Universe, which concerns today the understanding of inflation, dark matter and dark energy.

One more (indirect) way to search for New Physics is associated with the Physics of Flavor. The goal here is precise study of processes where fermions from one generation are transformed into fermions from another generation (change of flavor). Flavor Physics is currently a robust and crucial tool for the New Physics search, being potentially sensitive to a much higher scale of energy than achievable with future high-energy accelerators.

In general, the main direction of the New Physics search is "routed" today in the "responsibility region" of the (very) weak interactions. However, an essential element of the Standard Model is QCD, a well-developed quantum field theory of strong interactions. In any hadron process at high or low energy (i.e. LHC or beta decay), QCD is a main source of the formation of particles and inevitable background for the New Physics search. A detailed understanding of QCD effects is strongly requested for a correct interpretation of the experimental data.

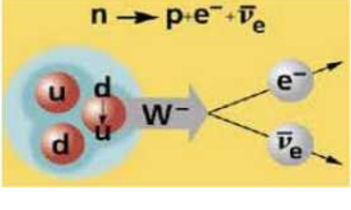
Perturbative QCD mainly due to the asymptotic freedom is an effective and well-working theoretical method which describes quark-gluon interactions at large momentum transfers (hard processes). However, Nonperturbative QCD, with its effect of confinement, inevitably presents everywhere at high energy in the form of parton distributions, fragmentation functions and other soft interactions of hadrons.

Nonperturbative QCD is, in fact, an important part of the Standard Model intended to explain from the first principles the dynamical chiral symmetry breaking (which generates about 98% of the visible mass in the Universe), the confinement, and the Entire Nuclear Physics — how hadrons are made from quarks and gluons and how they are producing all the diversity of atomic nuclei, interacting with each other.

These problems are very general and extremely complex, and to solve them one needs extra experimental information related to the search of new physics signatures in laboratory experiments and astrophysical observations as well as from the study of hadron matter properties in collider experiments and in compact stars. In addition to soft nonperturbative QCD processes (e.g. at the LHC), the main hopes for resolution of the long-standing problems of strong interaction physics are connected with the study of heavy-ion collisions at high energy, where the conditions are created for phase transformations in hot and dense hadronic matter.

Step-by-step addressing of the above fundamental issues requires studying a whole set of basic problems that are in the focus of the JINR Seven-year plan.

1) ***Neutron beta decay*** is a key process for precision test of the Standard Model. It is very sensitive to various extensions of the sector of charged weak currents, etc. Ultracold neutron physics is also very important basic research.

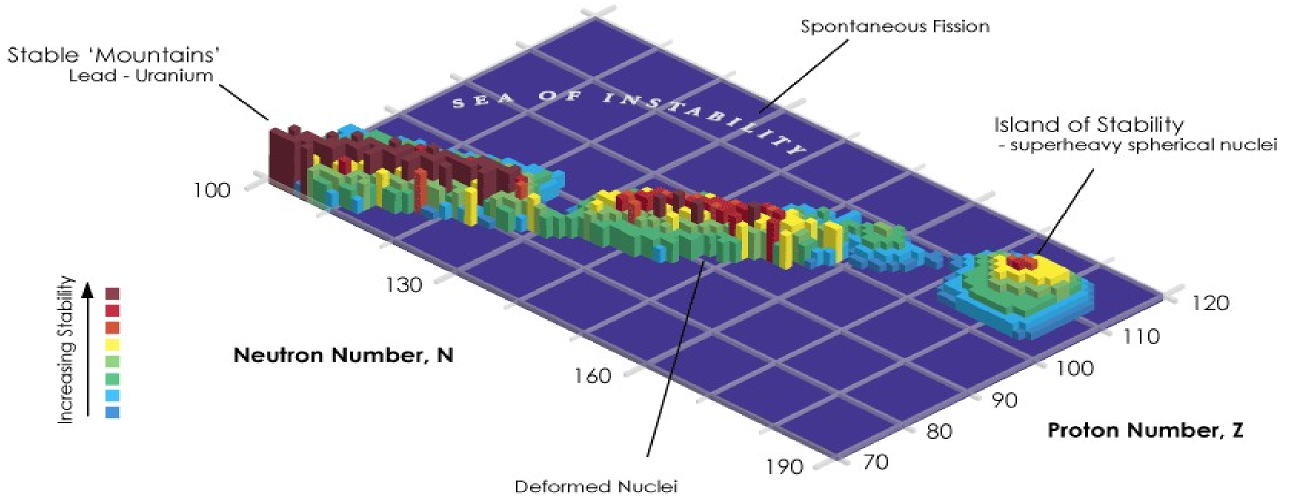


High-precision measurements of neutron beta decay (lifetime, angular correlations) are very important for determining the key elements of the Cabibbo-Kobayashi-Maskawa matrix and for understanding neutron structure in QCD. The properties of the neutron and neutron- induced nuclear reactions are very important for the study of many astrophysical processes. In particular, cross-sections for neutron capture reactions are crucial for understanding isotope formations in stars, supernovae, etc.

2) Any information about stable enough and unusual hadron states — glueballs, hypernucleus, light nuclei with large neutron excess, double(tetra)-baryons and other cluster configurations in nuclei — is crucial for understanding the QCD phenomena beyond perturbation theory.

This important information can be obtained via study of nuclear reactions induced by stable and radioactive ion beams of (exotic) light atomic elements.

3) **Heavy-ion physics** is a most rapidly developing area of nuclear physics at low and intermediate energy. Major achievements are the synthesis and study of nuclear, chemical and physical properties of transfermium ($Z > 100$) and superheavy elements (SHE), the formation and study of the properties of light exotic nuclei, study of reaction mechanisms with accelerated ions of stable and radioactive isotopes, etc.



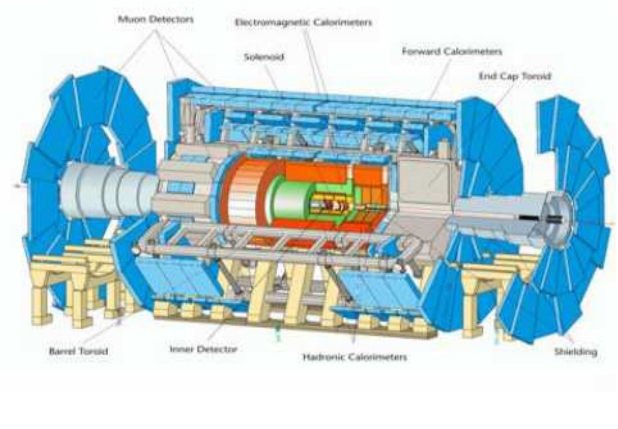
The prediction of the "island of stability" of SHE is a fundamental achievement of the macro-microscopic nuclear theory. Formation of SHE is a very rare event (pb). Moreover, the position and properties of the island is **strongly dependent on a particular nuclear model**. To specify the nuclear models it is necessary to study SHE with $Z = 113–118$ and to create new isotopes with $Z = 119, 120$. New data are needed about nuclear levels; data on fusion-fission at low excitation is important for determining the lifetimes of nuclei and optimization of their synthesis, etc.

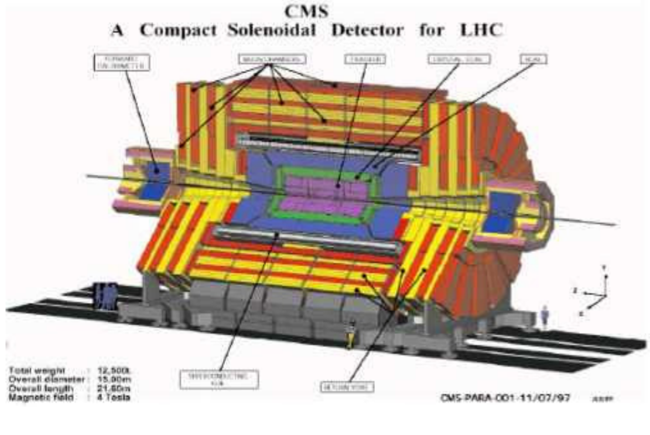
4) Study of the various characteristics of spontaneous and **neutron-induced fission** is of primary interest, particularly due to the availability of modern high-intensity neutron sources and due to the fact that nuclear fission is one of the most complex nuclear transformations associated with a profound redistribution of mass and charge of the original nuclei, producing highly deformed and excited fragments, etc.

All these nuclear physics studies **improve the nuclear models** (and understanding of nuclear structure) with a final goal to connect the models with basic concept of **nonperturbative QCD**.

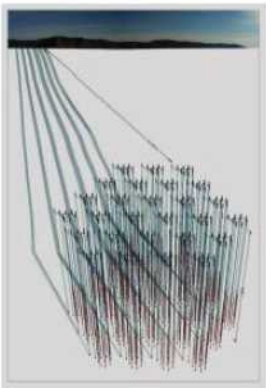
In accordance with the main directions of development of modern particle physics and astrophysics these are the following major goals of JINR's new Seven-year plan:

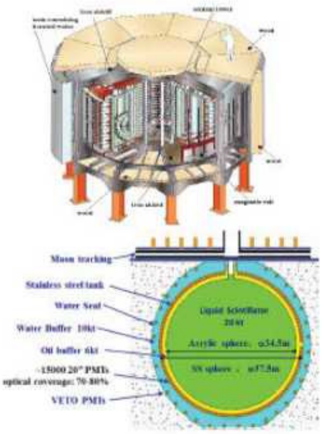
– **Direct search for New Physics with the LHC:** the main goal is to get fundamentally important results concerning the nature of the Higgs boson, the existence or non-existence of TeV-scale supersymmetry, extra dimensions of space and new interactions, the nucleon structure and properties of quark-gluon QCD matter, etc. — by means of full-scale participation in the international multi-purpose experiments ATLAS and CMS at 13–14 TeV.

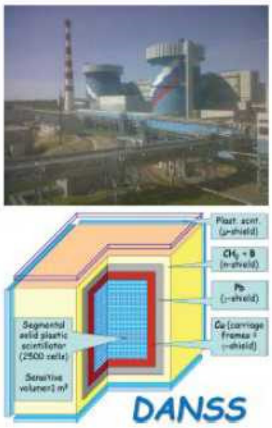




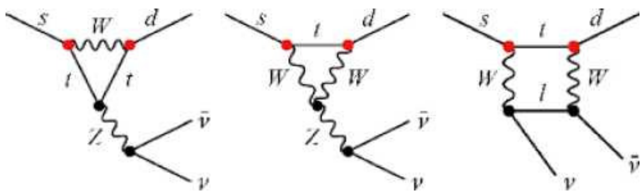
– **Neutrino programme:** research on neutrino astrophysics with unique Baikal-GVD neutrino telescope, basic and applied research with antineutrino beams of the Kalinin nuclear power plant, participation, due to the decisive contributions of JINR, in major international experiments (JUNO, SuperNEMO, NOvA, EURICA, DS, etc.), and establishment of JINR's corresponding research infrastructure at the most advanced level.





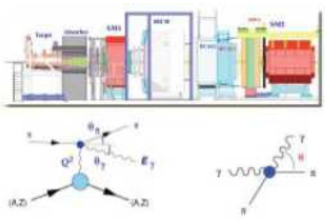


– in the **Flavor sector:** the main goal is to continue traditional research at JINR on the flavor physics of quarks and charged leptons by participating in the world's most important international experiments on the study of rare CP-violating kaon decays (like for example, $K \to \pi\nu\nu$) and search for muon to electron conversion on nuclei (Mu2e and COMET).



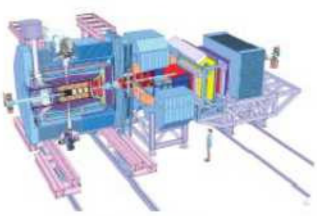
$$R_{\mu e} = \frac{\Gamma(\mu^- Al \to e^- Al)}{\Gamma(\mu^- Al \to \nu_\mu Mg)}$$

– in **Perturbative and nonperturbative QCD studies:** the goals are (a) to participate in major international experiments on nucleon and nuclear structure research (COMPASS, BESIII, PANDA, etc.) with the aim to obtain decisive information for a better understanding of QCD properties, hadron spin structure, etc.; (b) to continue basic research on neutron physics with IBR-2; (c) within an international collaboration on external sources of ultracold neutrons, to measure the key parameters of the neutron — beta decay, electric dipole moment, etc.



COMPASS

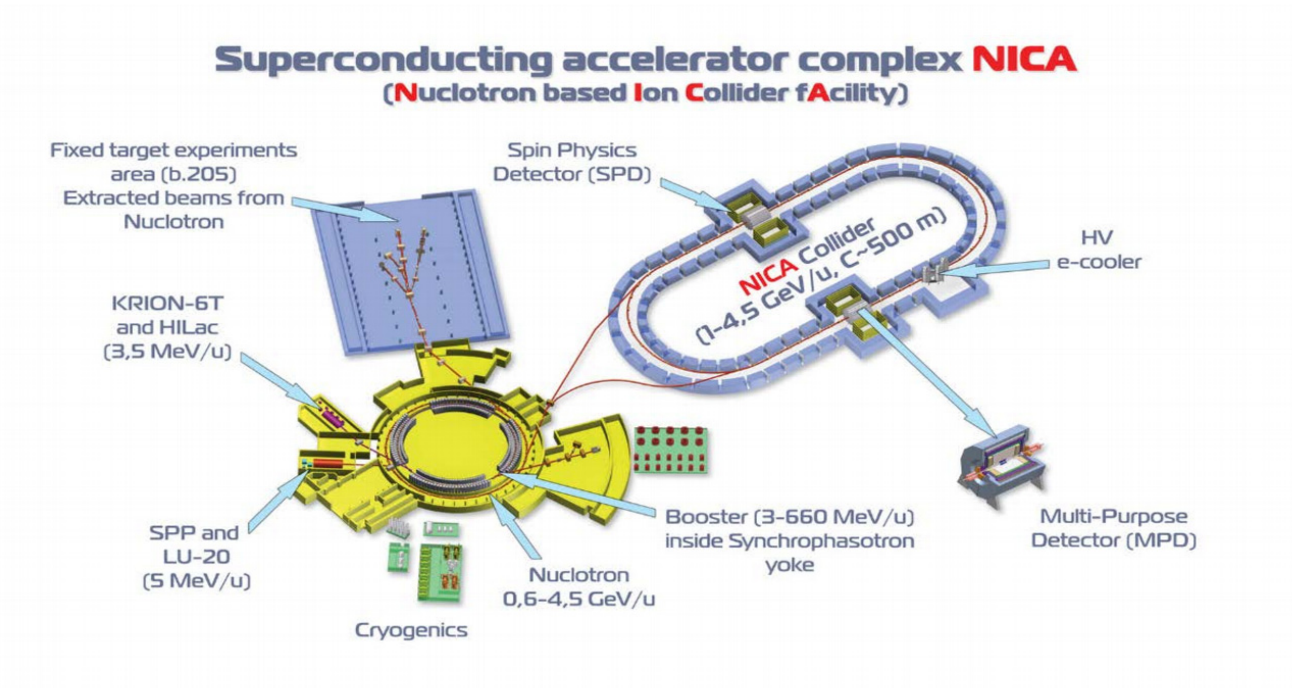
BESIII



PANDA

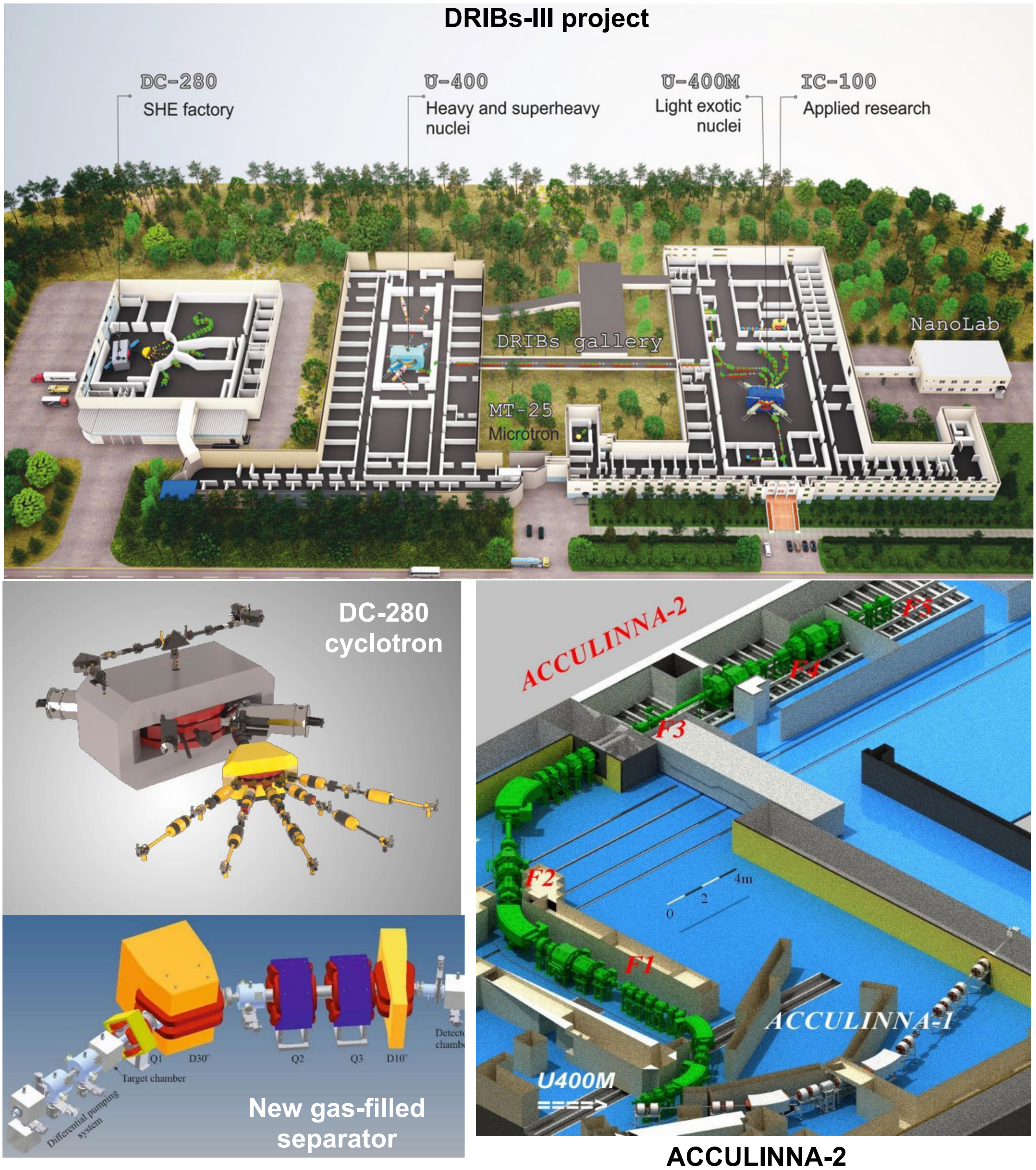
UCN setup

– in **Relativistic physics of atomic nuclei (heavy ions):** The experimental long-term task of JINR's megascience project NICA is investigation of hot and dense strongly interacting QCD-matter, search for a mixed phase and critical point in the QCD phase diagram *with the main goal to shed light on the poorly explored region of this diagram and clarify the basis of QCD in the nonperturbative regime and other theoretical approaches for the description of strongly interacting matter*. To this end, in the nearest seven years, JINR should put the NICA complex into operation, complete the installation of the BM@N and MPD detectors, and reach their design parameters to obtain new results in understanding hot-dense baryonic matter and its phase transitions. The NICA energy is believed to be particularly interesting because it corresponds to maximal net baryon density at the time of "freezing". At this energy, the system takes the maximum amount of space-time in the form of a mixed phase of quark-hadron matter (coexistence of hadron and quark-gluon phases).



– in **Modern nuclear physics** (due to interconnection with QCD and particle physics): the main goal is to enhance JINR's leadership in the physics of superheavy elements through a qualitatively new-level research at the JINR Factory of SHE on the synthesis and study of nuclear, physical and chemical properties of SHE isotopes, on the study of reaction mechanisms with stable and radioactive nuclei, on the search for new types of atomic nuclei decay, etc.

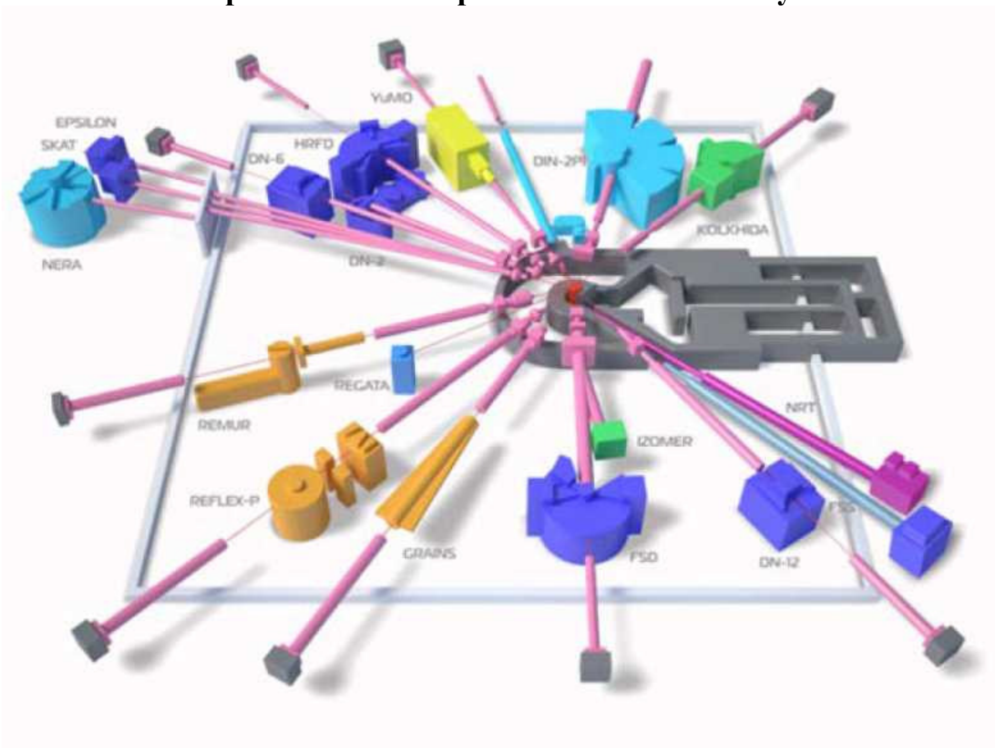
The final, most fundamental aim of this very important nuclear physics study is the connection with QCD basic principles.



ACCULINNA-2 fragment-separator

– in **Condensed matter physics**: the main goal is the development of experimental facilities in order to utilize efficiently the possibilities of the IBR-2 pulsed reactor — one of the three most intense neutron sources in the world. Studying the physics and chemistry of complex fluids and polymers, functional materials, novel physics of nanosystems brings new technological applications in power engineering, electronics, biology, medicine, etc. Since the planned lifetime of the IBR-2 reactor is limited to the middle 2030s, then within the framework of the new seven-year plan it is necessary to develop a concept and preliminary design of a new world-class facility for research with beams neutrons, and also begin the work on development of a fuel load for the new source. Also, as part of the current seven-year plan, activity will be started on modeling experimental infrastructure of the new source, including elements experimental installations with prototyping of individual components at the IBR-2.

Spectrometer complex of the IBR-2 facility



– in **Information Technology**, the main goal is to carry out fundamental promising and advanced research in the field of distributed computing, computational mathematics and computational physics aimed at the creation and use of new computing platforms, the development of new mathematical methods, algorithms and software by addressing urgent problems arising in experimental and theoretical studies. The solution of this task is closely related to a wide range of research conducted at JINR in high-energy physics, nuclear physics, condensed matter physics and nanotechnology as well as radiobiology and biophysics, and several other areas that require application and development of new approaches to modeling physical processes, processing and analysis of experimental data, including application in the studies within the NICA project, in the neutrino programme and in other strategic goals of the Institute. Within the modern computerized world, the advancement of the development in this direction is fundamental for the progress in all the other areas of the JINR research.

Development of the JINR facilities

The main aim of the **NICA project** is construction of an accelerator complex allowing to conduct research with colliding beams of high-intensity ions (up to Au^{+79}) with the average luminosity $L=10^{27}cm^{-2}s^{-1}$ at an energy range of $\sqrt{s_{NN}}$ = 4–11 GeV, also with beams of polarized protons ($\sqrt{s_{NN}}$ up to 26 GeV) and deuterons ($\sqrt{s_{NN}}$ up to 12 GeV) with longitudinal and transverse polarization as well as with extracted beams of ions and polarized protons and deuterons.

For effective use of the NICA complex opportunities, dedicated experimental set-ups will be built and put into operation: **BM@N** for the extracted beams, and **MPD** and **SPD** for the collider.

The following are the stages of construction, commissioning and development of elements of the NICA complex:

1. Commissioning of the NICA basic elements (in accordance with the schedule: booster — 2020; basic configuration of the collider — 2022–2023; design configuration of the collider — 2025). Development of experimental zones and extracted beam channels of the NICA complex — 2022.
2. Creation and start-up of an infrastructure for carrying out research in the field of hadron radiation therapy and other applied research in the fields of radiobiology and radiation-resistant microelectronics based on the VBLHEP accelerator complex — 2017–2023.
3. The start-up of the BM@N initial configuration for high-intensity light-ion beams extracted from the Nuclotron — 2017.
4. Completion of the upgrade and commissioning of the BM@N set-up for high-intensity heavy ion beams extracted from the Nuclotron — 2021.
5. Start-up of the MPD Stage I — 2022.
6. Commissioning of the MPD Stage II — 2025.
7. Putting into operation of the initial configuration of the SPD detector — 2025.

Development of the NICA complex (material costs, k$)

	2017	2018	2019	2020	2021	2022	2023	Total
Injection complex	1 739.5	2 633.2	2 497.3	1 325.5	1 368.1	1 464.4	1 215.0	**12 243.1**
Booster	4 157.4	4 334.0	3 240.2	1 464.3	1 148.5	454.0	354.1	**15 152.5**
Nuclotron	674.5	423.8	395.2	289.0	1 041.3	547.9	180.0	**3 551.6**
Collider	9 077.3	13 237.2	8 864.7	8 405.1	5 922.3	12 722.0	7 724.3	**65 952.9**
Cryogenic complex	933.8	1 278.4	511.2	1 252.3	785.7	520.0	80.0	**5 361.4**
BM@N	1 921.0	1 574.9	2 419.8	1 430.5	2 166.0	1 316.0	384.2	**11 212.4**
MPD	6 735.6	12 178.4	8 766.2	8 806.5	8 332.0	11 784.4	8 940.0	**65 543.1**
SPD	16.1	759.1	941.8	455.7	116.6	163.5	298.0	**2 750.9**
Magnet workshop	808.4	1 346.1	1 193.4	387.2	136.6	210.0	140.0	**4 221.7**
Computing	438.6	657.0	312.8	68.5	233.0	415.0	390.0	**2 514.8**
NICA infrastructure	11 815.0	8 013.5	9 712.6	8 315.2	28 063.8	23 702.9	6 994.4	**96 617.4**
Other expenses	7.4	25.8	17.1	14.6	0.0	0.0	0.0	**64.8**
Total	**38 324.6**	**46 461.3**	**38 872.4**	**32 214.4**	**49 313.9**	**53 300.0**	**26 700.0**	**285 186.6**

Full-scale realization of the project DRIBs-III (**D**ubna **R**adioactive **I**on **B**eams), as a major part — the start-up of the **Factory of Superheavy Elements** (SHE Factory) based on a specialized cyclotron, DC-280, together with experimental instruments of a new generation is the major task of the Flerov Laboratory of Nuclear Reactions for the period 2017–2023. This will considerably expand the possibilities for carrying out fundamental and applied research in nuclear physics at JINR at the highest level in broad cooperation with scientific centres of the Member States and other countries.

The following are the main stages of construction, commissioning and development within the DRIBs-III project:

1. Production of beams of the DC-280 cyclotron with smoothly variable energy; attaining the maximum beam intensity (up to 10 p·A) for nuclei with A<100; production of intense beams of rare stable isotopes (^{36}S, ^{48}Ca, etc.) and beams of long-lived radioactive nuclei ^{36}Ar, ^{50}Ni etc.; development of the infrastructure for accommodation and use of experimental set-ups in other research centres —- 2017–2023.
2. Reconstruction of the U400 cyclotron (U400R) and experimental hall aimed at extending the range of accelerated ions from helium to uranium; decrease of the energy spread to 0.3% for ion beams with smoothly variable energy within the range of 0.8-25 MeV·A; decrease of power consumption and increase of work stability during long-term irradiation runs; production of beams of rare stable nuclei, long-lived isotopes and short-lived ($T_{1/2}$>0.1 s) nuclei injected into the ion source or directly into the external injection vertical channel; expansion of the total area of the experimental hall up to 1500 m^2 suitable for autonomous work in each of the six radiation-shielded caves — 2020–2023.
3. Reconstruction of the U400M cyclotron aimed at producing intense beams of radioactive ions, advancing toward the boundaries of proton and neutron stability of nuclei, and conducting research on nuclear interactions with maximum proton and neutron excess employing a new powerful ACCULINNA-II separator — by 2020.
4. Development of long-running experimental set-ups: separators, multifunction detection systems.

Financing and implementation schedule for the DRIBs-III project for 2017-2023 (k$)

	2017	2018	2019	2020	2021	2022	2023	Total
SHE Factory								
Completion of the construction of the experimental building	2 800.0	1 285.0	45.0	5.0	0.0	0.0	0.0	**4 135.0**
DC-280 Accelerator	1 230.0	140.0	450.0	255.0	0.0	0.0	0.0	**2 075.0**
Creation of new physical installations	3 440.0.	1 450.0	1 060.0	2 370.0	2 420.0	2 100.0	1 400.0	**14 240.0**
U400R Accelerator complex								
Assembly hall construction	90.0	455.0	460.0	1 460.0	720.0	0.0	0.0	**3 185.0**

Construction of an experimental hall	10.0	240.0	65.0	320.0	1 550.0	3 400.0	2 700.0	**8 285.0**
Modernization of the U400 cyclotron	0.0	0.0	0.0	410.0	140.0	2 200.0	2 000.0	**4 750.0**
Modernization of the U400 cyclotron								
Modernization of the U400M cyclotron	2 240.0	1 820.0	1 760.0	1 500.0	1 550.0	250.0	0.0	**9 120.0**
DC-140 Accelerator complex								
The creation of the cyclotron DC-140 (upgrade U200 → DC-140)	0.0	0.0	0.0	0.0	2 500.0	2 600.0	1 900.0	**7 000.0**
Class I radiochemical complex project								
Class I RCC project	0.0	0.0	0.0	0.0	200.0	500.0	500.0	**1 200.0**
Creation of new and reconstruction of existing installations on the U400R and U400M								
Electromagnetic separators, detection systems	3 290.0	3 320.0	3 100.0	2 930.0	2 260.0	1 350.0	2 370.0	**18 620.0**
Experiment support								
Experimenting	2 990.0	2 850.0	2 900.0	1 390.0	2 750.0	2 600.0	2 200.0	**17 680.0**
Total	**16 090.0**	**11 560.0**	**9 840.0**	**10 640.0**	**14 090.0**	**15 000.0**	**13 070.0**	**90 290.0**

Beam time (on target) (h)

	2017	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**Total**
U400/U400R	5 000	5 000	5 000	5 000	5 000	3 000	0	**28 000**
U400M	5 000	5 000	5 000	2 500	0	2 000	5 000	**24 500**
DC-280	0	0	3 000	5 000	5 000	5 000	5 000	**23 000**
Total	**10 000**	**10 000**	**13 000**	**12 500**	**10 000**	**10 000**	**10 000**	**75 500**

IBR-2 is JINR's basic facility for neutron studies of condensed matter, one of the most powerful pulsed neutron sources in the world and **the only one in the JINR Member States**. Under the previous Seven-year plan, first cryogenic moderators were constructed; the number of the reactor spectrometers for condensed matter investigations increased from 11 to 14, and significant upgrades of a number of available spectrometers were carried out.

The programme for the development of the IBR-2 reactor for 2017–2023 assumes:

1. Development and operation of the complex of cryogenic moderators. Purchase and commissioning of a new refrigerator for beam lines 4-6. Development of control and monitoring systems of the complex of cryogenic moderators CM-201, CM-202, CM-203. Development and construction of a back-up movable reflector MR-3R.

2. Upgrade of the reactor technological equipment with expiring service life (air heat exchangers, electromagnetic pumps, etc.).

New neutron source of JINR

1. Development of a conceptual design of a new neutron source.
2. Development of a preliminary design of a new neutron source.
3. Development of a fuel load for a new source.
4. Modeling the experimental infrastructure of the new source, including elements of experimental installations with prototyping of individual components at the IBR-2.

The programme for the development of the IBR-2 spectrometer complex will be aimed at:

1. Implementation of the final configuration and development of new spectrometers DN-6, GRAINS, spectrometer of tomography and radiography, FSS.
2. Upgrade of the existing spectrometers aimed at improving their technical parameters, extending the experimental capabilities and ensuring trouble-free operation. This includes neutronbeam-forming systems, neutron detectors, sample environment systems, cryostats and cryomagnetic systems, upgrade of electronics and software of data acquisition systems.
3. Simulation, development and construction of the basic configuration of a new small-angle scattering spectrometer.

Financing schedule for IBR-2 and spectrometers for 2017-2023 (k$)

	2017	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**Total**
Work on the creation of the final configuration and development of new spectrometers DN-6, GRESINS, tomography and radiography, FSS	350.0	427.1	413.5	115.6	81.8	97.6	81.9	**1 567.5**
Modernization and reconstruction of the existing spectrometers of the IBR-2 reactor	578.6	1218.8	518.5	1159.2	90.0	151.6	53.2	**3 769.9**
Development and creation of the main configuration of a new small-angle scattering spectrometer	115.0	228.7	199.0	196.2	411.0	270.3	193.1	**1 613.3**
Purchase of materials and equipment through grants from Plenipotentiaries, Cooperation Programs and Joint Projects with non-participating countries	1045.4	779.6	688.7	728.8	0	0	0	**3 242.5**
Optical research methods	196.7	87.9	87.4	86.5	103.0	61.6	42.2	**665.3**
Development of the IBR-2 reactor with a complex of cryogenic moderators	1537.8	2 893.0	3 214.0	1 075.5	2 652.7	1 996.7	1 426.2	**14 795.9**
Development of monitoring and control systems for cold neutron moderators and executive mechanisms of spectrometers	263.8	525.3	595.3	525.9	341.0	302.4	216.0	**2 769.7**

Development of detectors, sample environment systems, data collection and storage systems; development of information and computing infrastructure of FLNP	535.6	1 066.5	1 184.2	1 048.0	1 042.3	619.9	387.4	**5 883.9**
Operation of the IBR-2	219.5	151.9	312.7	384.3	317.5	350.0	350.0	**2 085.9**
Total	**4842.4**	**7 378.8**	**7 213.3**	**5 320.0**	**5 039.3**	**3 850.0**	**2 750.0**	**36 393.8**

SOLCRYS Structural Research Laboratory

Condensed matter research at JINR is carried out in the field of studying new materials (catalysts, polymers, etc.), nanomaterials (nanoparticles, nanocomposites, etc.), materials under extreme conditions (superconductors, perovskites, etc.) and biomaterials (proteins, DNA, etc.). Research methods based on scattering of synchrotron radiation will be developed on the basis of the National Synchrotron Radiation Center SOLARIS of the Jagiellonian University in Krakow (Poland), where JINR proposes to create a new Laboratory for Structural Research SOLCRYS. It is planned to create three measuring stations:

- for macromolecular X-ray crystallography;
- for small-angle X-ray scattering;
- for powder diffraction.

SOLCRYS laboratory construction program for 2020–2023:

1. Expansion of the existing experimental hall to accommodate the end stations of the crystallographic line, as well as a laboratory for sample preparation.

2. Development and development of technical infrastructure to the extent necessary for the installation and proper operation of the research equipment of the SOLCRYS laboratory.

3. Design, acquisition and installation of research infrastructure, including:

a) development, purchase and installation of a superconducting wiggler as a radiation source in the X-ray range with an upper photon energy of at least 20 keV;

b) design, purchase and installation of a research line for diffraction studies, including:

— a vacuum system that separates the synchrotron and the line — the so-called front end;

— line infrastructure, consisting of vacuum systems, beam guidance and control systems, optics and monochromators;

c) design, purchase and installation of a measuring station for diffraction studies;

d) construction of measuring stations for studies of small-angle X-ray scattering (SAXS) and wide-angle X-ray scattering (WAXS);

e) design and assembly of control systems, as well as data collection and storage systems;

f) construction of facilities for the preparation of samples.

JINR's traditional research activities in the field of **nuclear physics with neutrons** will be carried out at a high-resolution neutron source — **IREN facility**.

Further development of the **IREN** facility in 2017–2023 is connected with improvement of the accelerator's systems and with modernization of the infrastructure of the experimental hall and pavilions. It includes:

1. Change-over to new klystrons to make it possible to increase the frequency of neutron pulses from 50 Hz to 120 Hz.

2. Optimization of the electron source, electron beam formation and its transportation to increase the accelerator's efficiency.

3. Modernization of the experimental hall to provide world-class infrastructure of the experimental facilities.

Funding schedule for the IREN facility for 2017–2023 (k$)

	2017	2018	2019	2020	2021	2022	2023	Total
Maintenance and operation	230.0	200.7	478.8	157.5	28.8	150.0	150.0	**1 395.8**
Improvement of accelerator systems	1 058.5	932.2	358.5	0.0	0.0	0.0	0.0	**2 349.2**
Total	**1 288.5**	**1 132.9**	**837.3**	**157.5**	**28.8**	**150.0**	**150.0**	**3 745.0**

The Gigaton Volume Detector **(BAIKAL-GVD)** Facility in Lake Baikal is an extension of the R&D work on the first phase performed over the past several years by the BAIKAL Collaboration. The optical properties of the deep-water lake have been established, and the detection of high-energy neutrinos has been demonstrated with the existing detector NT200/NT200+. This achievement represents a proof of the concept for commissioning a new instrument, BAIKAL-GVD, with superior detector performance and an effective telescope size at or above the kilometer-scale.

Within the framework of the current seven-year plan, JINR's obligations regarding the creation of the BAIKAL-GVD neutrino telescope are to commission 12 clusters and complete the first stage of the detector construction. The years 2022–2023 will be used to study the possibility of technological modernization of the BAIKAL-GVD unit in preparation for the next stage of development.

The second-stage neutrino telescope BAIKAL-GVD will be a new research infrastructure aimed primarily at studying astrophysical neutrino fluxes. The detector will utilize Lake Baikal water instrumented at depth with optical sensors that detect the Cherenkov radiation from secondary particles produced in interactions of high-energy neutrinos inside or near the instrumented volume. The concept of BAIKAL-GVD is based on a number of evident requirements to the design and architecture of the recording system of the new array: the utmost use of the advantages of array deployment from the ice cover of Lake Baikal, the extendibility of the facility and provision of its effective operation even in the first stage of deployment, and the possibility of implementing different versions of arrangement and spatial distribution of light sensors within the same measuring system.

Financing schedule for the BAIKAL-GVD project for 2017–2023 (k$)

	2017	2018	2019	2020	2021	2022	2023	Total
PMT Hamamatsu R7081-100	1 930.0	1 974.0	1970.0	2 040.0	2 050.0	1 000.0	0.0	**10 964.0**
Optical modules with connectors	2 315.0	1 538.0	1 331.0	1 365.0	1 000.0	700.0	0.0	**8 249.0**
Electronics and computing	2 550.0	1 920.0	1 850.0	1 900.0	1 120.0	1 000.0	1 400.0	**11 740.0**
Submarine cables	519.0	583.0	1 258.0	2 020.0	2 050.0	500.0	0.0	**6 930.0**
Local infrastructure	846.0	835.0	731.0	625.0	798.1	800.0	800.0	**5 435.1**
Total	**8 160.0**	**6 850.0**	**7 140.0**	**7 950.0**	**7 018.1**	**4 000.0**	**2 200.0**	**43 318.1**

Planned schedule for GVD production and development

	2017	2018	2019	2020	2021	2022	2023	Total
Installing clusters by year	1	2	2	2	2	2	1	**12**
Clusters in the detector	2	4	6	8	9	11	12	**12**
Production of optical modules	600	600	600	600	600	600	300	**3 556**

Particle Physics and High-Energy Heavy-Ion Physics

Scientific research in the field of elementary particle physics and high-energy heavy-ion physics can be classified into four interrelated directions — the energy-increasing accelerator direction (the Energy Frontier), the intensity-increasing accelerator direction (the Intensity Frontier), the accuracy-increasing non-accelerator direction (the Accuracy Frontier), and the particle astrophysics direction (the Cosmic Frontier). In view of these general directions, within the framework of the new Seven-year plan, JINR will focus on the following main topics:

1. Particle physics research, including particle spectroscopy, spin physics, neutrino physics and rare phenomena studies (covering the Energy, Intensity, Accuracy, and Cosmic Frontiers), aimed at extending the Standard Model and discovering new fundamental laws of Nature.

2. High-energy heavy-ion physics research (Energy and Intensity Frontiers) aimed at establishing unique properties of hadronic matter under conditions of phase transitions between quark and hadronic states of matter.

3. Development of new-generation detector systems and accelerator complexes, theoretical support of the current and planned experimental investigations, development and maintenance of high-performance telecommunication links and computing facilities at JINR, aimed at providing a comprehensive support for realization of the scientific tasks envisioned by the seven-year plan.

The new Seven-year plan in the field of particle and high-energy heavy-ion physics will be implemented by efforts of four JINR Laboratories (VBLHEP, DLNP, LIT, and BLTP) both on the JINR in-house facility base — the NICA accelerator complex, and within the framework of international partnership programmes at the world's largest accelerator facilities in the experiments with essential contribution made by JINR staff.

JINR will continue to participate in the development of accelerator subsystems and detectors within the ILC project.

Within the framework of the FLASH and XFEL international projects, JINR physicists participate in the development of diagnostic systems of ultrashort bunches in the linear accelerator, X-ray, large cryogenic systems.

The study of hot and dense baryonic matter and its phase transformations will be performed at the NICA complex, whose basic configuration is planned to be carried out in the second half of the seven-year period. Experiments will be carried out with extracted beams of the Nuclotron at the BM@N set-up and in the collider mode at MPD in heavy-ion collisions at the energy range $\sqrt{s_{NN}} = 4$–11 GeV. The launching of the NICA complex and the mentioned detectors, their final adjusting to the design objectives, and obtaining new experimental results will be the primary tasks for VBLHEP in the next seven years.

The VBLHEP research groups will continue taking part in the study of nuclear matter properties under extreme conditions, in the search for the onset of quark deconfinement and possible phase transitions within common research programmes in the STAR experiment at RHIC, BNL, in the NA6I experiment at CERN's SPS, in the ALICE experiment at CERN's LHC, and in the CBM experiment at FAIR, GSI. The scope of JINR's participation will be assessed and possibly limited depending on the progress in implementing the NICA project as well as on the necessity to consolidate work at the JINR accelerator complex.

Expected results:

I. The start-up of the BM@N first configuration for high-intensity light-ion beams extracted from the Nuclotron. Obtaining first results in the research programme of the BM@N experiment: study of yields of hadrons, hyperons, and light nuclei — 2020–2021.

2. Obtaining results at BM@N using high-intensity heavy-ion beams, including ions of gold. Study of elliptic and directed flows, production of hyperons with $S = 2$ and hypernuclei — 2023–2024.

3. The start-up of the MPD Stage I, obtaining first results in the research programme to study the properties of hot and dense baryonic matter in the central rapidity range, to search for phase transitions (observables - particle yields and spectra) including partial restoration of chiral symmetry (observables - yields of di-leptons), and to search for the critical end-point (observables - event-by-event fluctuations, particle correlations) — 2022–2023.

4. Commissioning of the MPD Stage II. Beginning of the research programme with the MPD detector in the available phase space region — 2025.

5. Obtaining new results in the energy scan programme in the experiments NA61 (SPS) and STAR (RHIC) — 2017–2023.

6. Obtaining new results in the femtoscopy programme in the ALICE experiment (LHC), participation in ALICE upgrade — 2017–2023.

7. Settlement of commitment in the development and commissioning of the CBM set-up under JINR's obligations in accordance with the NICA-FAIR joint research programme — 2017–2023.

The study of nucleon spin structure and other polarization phenomena in nucleon–nucleon and nucleon-nuclei interactions as well as in few-nucleon systems will be carried out at the VBLHEP accelerator complex and at CERN and BNL. Both fixed-target experiments with Nuclotron polarized beams and NICA collider experiments at the SPD detector will be performed at VBLHEP. Construction of SPD is planned to be implemented within the next Seven-year plan according to the technical design project which is to be prepared. The SPD research programme will extend the ongoing programme of hadron structure and spectroscopy investigations with high- intensity muon and hadron beams in the COMPASS experiment (CERN's SPS) as well as with polarized proton beams at STAR (BNL), in which JINR will continue its participation during 2017–2023.

Expected results:

1. Stage-by-stage commissioning of the polarized beam channels at the Nuclotron and of the infrastructure necessary to support the experimental research of polarization phenomena within the framework of an international collaboration — 2017–2023.

2. Carrying out the research programmes of the DSS and ALPOM-2 experiments with Nuclotron polarized beams. Approval and realization of new experiments developed to study nucleon spin structure and other polarization phenomena (both in nucleon-nucleon and nucleon-nuclei interactions and in few-nucleon systems) with Nuclotron beams —2017–2023.

3. Putting the SPD start-up configuration into operation at the NICA collider — 2026.

4. Obtaining new results on nucleon spin structure in the COMPASS (SPS) and STAR (RHIC) experiments in MMTDY, DVCS and SIDIS processes — 2017–2023.

The search for physical phenomena beyond the Standard Model will be continued in the CMS and ATLAS experiments at CERN's LHC.

JINR will take part in the upgrade of detectors during LHC shut-down periods in 2018–2019 and 2022–2024 and will continue analysis of data from the LHC.

The JINR group is supposed to take part in a search for weakly interacting particles of dark matter which is proposed to be conducted at CERN's SPS. JINR will also participate in a search for charged lepton flavor violation in muon-to-electron conversion in the **μ2e** (FNAL) and **COMET** (J-PARC) experiments.

Expected results:

1. Obtaining new experimental results within the framework of the programme aimed at verification of the Standard Model (SM) predictions and a search for physics beyond the SM at CMS and ATLAS. Settlement of commitment on detector upgrades under the JINR contract — 2017–2023.

2. Preparation and launch of the experiment aimed at a search for weakly interacting particles of dark matter using SPS beams — 2017–2023.

3. Achievement of an upper limit for muon-to-electron conversion at a level of $6 \cdot 10^{-17}$ in the μ2e and COMET experiments — 2020–2023.

The JINR team will continue a series **of precise experiments to study kaon decays**, including those with direct CP violation, in the NA62 experiment at CERN's SPS.

Expected results:

1. Obtaining new data on extra rare decays of charged K-mesons in the NA62 experiment – 2017–2023.

2. Precise determination of the SM parameters, obtaining new knowledge about the nature of CP violation and search for the occurrence of new physics beyond the SM.

JINR will continue to participate in the preparation of the physics programme of the **FAIR** complex, which includes a wide range of tasks concerning the key aspects of QCD. The antiproton beam with an energy range from 1 to 15 GeV/s will allow one with the PANDA set-up to take precision measurements on the spectroscopy of charmonium and charmed hadrons, on the search for exotic hadron states and research on the nature of hadron mass modification due to the dense hadron environment. In the PANDA experiment, JINR plans to take part in construction of the muon system, the superconducting solenoid and quartz radiators of the electromagnetic calorimeter. The main part of work will be financed within the Russian contribution to FAIR.

In the field of accelerator physics and technology, in addition to work on the construction of elements for the NICA accelerator facility and participation in the preparation of ILC systems, collaborative effort on the construction of the FAIR complex is planned under the Russia-FAIR and JINR-FAIR programmes.

Neutrino physics and astrophysics offer promising possibilities to study the fundamental, key issues of modern elementary particle physics. Observation of **neutrino oscillations**, which led to the 2015 Nobel Prize in Physics, requires neutrinos to have non-zero mass as well as lepton number non-conservation.

DLNP is taking part in the leading experiments studying neutrino oscillations such as the **Daya Bay** reactor neutrino experiment, which discovered a non-zero value of the mixing angle θ_{13} — a result garnering the 2016 Breakthrough Prize in Fundamental Physics.

At present, neutrino physics has entered a new era of precision measurements and new objectives focusing on studies of neutrino mass hierarchy and CP violation.

The mass hierarchy problem will be addressed by JINR scientists with the help of two complementary techniques using reactor and accelerator neutrinos in the **JUNO** and **NOvA** experiments respectively.

CP violation in the lepton sector will be addressed with help of another accelerator experiment — **DUNE**, in which JINR plans to enhance its participation.

The study of double-beta decay processes is also of high priority at DLNP and is conducted within the framework of the **GERDA-MAJORANA (G&M)** and **SuperNEMO** projects.

DLNP will continue to participate in the study of solar neutrinos in the **BOREXINO** experiment.

DLNP plans an increasing international large-scale participation in the **BAIKAL-GVD** experiment focusing on the detection of ultrahigh-energy cosmic neutrinos. A continuous increase of the observable volume up to 0.4 km^3 in parallel with data taking is foreseen during 2017–2023.

In the next seven-year period, the internationally recognized Neutrino Programme of JINR will be realized in several stages unique for each experiment. In addition to the development of the **BAIKAL-GVD facility**, which was covered in detail in the previous section, the following are the plans concerning the JUNO, NOvA and DUNE experiments:

During 2017–2020, JINR aims to complete its major contribution to the construction of the **JUNO** experiment. In particular, JINR specialists:

- will build a power supply for 20 thousand of JUNO's PMT;
- will build a number of PMT scanning stations developed by JINR for detailed characterization of JUNO's PMT at experimental site;

– will complete part of its financial contribution, in the form of use of scintillation detectors of the OPERA experiment in the JUNO experiment as a veto-system; will develop methods to control these sensors and provide necessary equipment for the installation at the experiment site;

– will develop methods and seek for a hardware contribution in terms of the PMT protection against the Earth's magnetic field;

– will build a computer farm for simulation and analysis, including the development of its own computer database for processing data at JINR.

JINR aims to maintain the **NOνA** remote control room used not only for JINR, but also by some institutions of the Russian Federation (INR, FIAN).

During 2019–2023, JINR specialists plan to conduct R&D work on the calorimetry of the near detector of DUNE and on the construction of the electromagnetic calorimeter, which is based on the unique experience of JINR.

Financing schedule (k$)

	2017	2018	2019	2020	2021	2022	2023	Total
JUNO, NOνA/DUNE projects	1 220.0	1 290.0	3 440.0	930.0	582.7	1 000.0	1 000.0	**9 462.7**

JINR plays a leading role in advanced reactor neutrino experiments in the immediate vicinity of nuclear reactors (DANSS, GEMMA / νGeN). The development of experimental techniques, synergy with other low-background projects of JINR, allows and will allow in the future to carry out new research at the forefront of science. The research results will be:

– search for neutrino oscillations to sterile states on a short baseline with the world's best sensitivity; - search for the neutrino magnetic moment at a level better than 9×10^{-12} μ_B;

– detection of coherent scattering of neutrinos on nuclei (CEνNS) in the zone of complete coherence;

– the use of CEνNS for the precision study of the electroweak sector and the search for New Physics beyond the Standard Model;

– monitoring of in-core processes.

	2017	2018	2019	2020	2021	2022	2023	Total
Experiments at the Nuclotron: DSS, ALPOM-2, HyperNIS, FAZA-3, new projects	150.0	150.0	205.0	205.0	1 005.0	3 005.0	2 905.0	**7 625.0**
VBLHEP: experiments in CERN, BNL, GSI / FAIR	1 566.0	1 736.0	1 879.0	1 709.0	1 629.0	1 649.0	1 649.0	**11 817.0**
Neutrino program	1 880.0	1 934.0	1 993.0	1 533.0	1 574.0	1 617.0	1 662.0	**12 193.0**
DLNP: ATLAS	1 020.0	1 200.0	1 460.0	2 550.0	1 540.0	930.0	960.0	**9 660.0**
DLNP: other projects	820.0	830.0	840.0	850.0	860.0	870.0	880.0	**5 950.0**
Total	**5 436.0**	**5 850.0**	**6 377.0**	**6 847.0**	**6 608.0**	**8 071.0**	**8 056.0**	**47 245.0**

Nuclear Physics

The following main areas of research in the field of low-energy nuclear physics will be further developed in 2017–2023: synthesis of superheavy elements using heavy ions and study of their physical and chemical properties, basic research with neutrons, and applied investigations.

The unique opportunities of JINR's heavy-ion accelerators and experimental research instruments have led to the establishment of broad international collaborations with research centres of the JINR Member States and other countries.

Synthesis of superheavy elements and study of their nuclear properties

Construction of the Factory of Superheavy Elements will allow FLNR during 2017–2023 to conduct an in-depth study of the nuclear properties of isotopes of superheavy elements with $Z = 113$–118. Comparative examinations of reactions between actinide targets and ^{48}Ca and between actinide targets and heavier projectiles, like ^{50}Ti, ^{54}Cr, and ^{58}Fe, will make it possible to proceed to the synthesis of elements with $Z = 119$, 120. Significant attention will be given to experiments on the synthesis of new isotopes of superheavy elements to determine the borders of the “island” of increased stability of SHE.

Investigation of incomplete fusion reactions of massive nuclei

The next step in research of heavy and superheavy neutron-rich nuclei will be investigation of deep inelastic transfer and quasi-fission reactions as an instrument for the synthesis of heavy nuclei with a large neutron excess and study of the influence of shell effects on reaction mechanisms.

Synthesis of new nuclides in the heavy nuclei region and study of their properties

Heavy neutron-rich nuclei located in the region Z = 60–90 near the neutron closed shell $N = 126$ will be studied in multinucleon transfer reactions using high-intensity beams of heavy ions.

Nuclear structure of elements of the “second hundred”

Experiments on α-, β-, and γ-spectroscopy of heavy and transfermium isotopes, which will allow physicists to obtain data on structures of nuclear levels and to clarify the parameters of models describing SHE properties, will be continued.

Study of mechanisms of reactions with stable and radioactive nuclei, search for new decay modes

Set-ups equipped with cryogenic targets ^{3}He, ^{4}He, H_2, D_2, T_2 and multiparameter charged-particle, neutron, and gamma-quanta detecting systems will be used to implement programmes to search for 2*n* and 4*n* radioactivity and to study 2*p* radioactivity as well as 2*n*, 4*n*, 2*p*, and 4*p* decays near the borders of nuclear stability.

Study of characteristics of reactions with weakly bound stable and radioactive nuclei in the vicinity of the Coulomb barrier as well as mechanisms of nuclear reactions with cluster nuclei will be continued. These investigations will allow the role of exotic nuclei in astrophysical nucleosynthesis to be evaluated.

Nuclear physics with neutrons

Research in the field of nuclear physics with neutrons will be carried out at the IREN facility. Experiments will also be carried out at the IBR-2 reactor (mainly those that require high neutron fluxes), at the EG-5 facility (experiments with fast neutrons, low-background measurements and applied studies) and at external neutron sources.

The research activities will be continued in three main directions:

1. Investigations of the violation of fundamental symmetries in neutron-nuclear interactions and related data

In 2017–2023, efforts of the corresponding research teams will be focused on the high-priority investigations related to the study of the violation of fundamental symmetries in neutron-nuclear interactions. The main tasks in this field are:

– Search for neutral currents in weak nucleon-nucleon (NN) processes in experiments to measure P-odd asymmetry in the reactions of slow polarized neutrons with light nuclei, in particular measurements of P-odd asymmetry in the $^3He(n,p)^3H$ reaction with cold polarized neutrons (ILL, PIK).

– Investigation of T-odd and P-odd effects in fission. Measurement of characteristics and correlations in the emission of neutrons, gamma quanta and light charged particles in fission (IREN, IBR-2, ILL, FRM-2).

– Investigations of T-odd, P-odd and P-even effects in the (n, γ), (n, p), (n, α) reactions in the resonance neutron energy range (IREN, EG-5, n_TOF).

– Investigation of prompt neutrons produced in nuclear fission and properties of superfluidity of fission fragments (IREN).

– Measurements of total and partial neutron cross-sections, angular correlations, multiplicity fluctuations, yields of reaction products in neutron-nuclear interactions (IREN, EG-5, n_TOF).

2. Investigations of fundamental properties of the neutron and UCN physics

The research activities in the field of UCN physics during 2017–2023 will be focused on the preservation and promotion of the existing scientific school. The world trend in the development of this research area is to build high-density UCN sources. Putting a UCN source with a density of 10^3 n/cm^3 into service will open new prospects for improving the accuracy of precision experiments with UCN, for implementing new techniques and extending the area of application of ultracold neutrons (for example, use of UCN to study the surface and related physical phenomena). JINR is planning to actively participate in the development and construction of such a source at the most intense neutron sources: PIK reactor (Gatchina, Russia) or reactor in ILL (Grenoble, France).

The most exciting physics problem that can be addressed with a high-density source is to determine the neutron lifetime with an accuracy of ~ 0.1 s. The solution of this problem will be a toppriority task for the seven-year period. The use of an intense UCN source will require the application of new experimental techniques and approaches which should be preliminarily developed and tested.

The available neutron sources at JINR do not allow high-density UCN sources to be developed, but such a source would be indispensable for test experiments as well as for attracting and training young specialists. One of the tasks in this direction in 2017–2023 is to study the possibility of developing a source of very cold neutrons (VCN) at the IBR-2 reactor and a UCN source on its basis. The development of a VCN source itself has interesting prospects for using it to solve problems both in fundamental physics and condensed matter investigations.

3. Applied and methodological research will include:

- Studies using neutron activation analysis at the REGATA facility of the IBR-2 reactor and atomic absorption spectrometer (AAS) within the framework of international and national projects in the field of life sciences.

- Non-destructive analysis of the elemental composition of objects using thermal, resonance and fast neutrons by neutron and gamma spectrometry.

- Development and application of the tagged neutron method for fundamental studies of interactions of fast neutrons with nuclei. Application of the method for elemental analysis.

- Analysis of surfaces of solids and nanostructures at the EG-5 accelerator. Development of a microbeam based on this accelerator.

- Simulation and calibration of neutron detectors for space vehicles.

Financing schedule (k$)

	2017	2018	2019	2020	2021	2022	2023	Total
Fundamental research of nuclear reactions under the action of neutrons	1 020.6	732.5	739.0	696.2	88.5	300.0	300.0	**3 876.8**
Investigations of the fundamental properties of the neutron, UCN physics	180.0	195.0	168.5	145.0	0.0	220.0	220.0	**1 128.5**
Applied and methodical works	518.4	331.4	929.0	427.6	0.0	180.0	180.0	**2 566.4**
Modernization of the IREN Experimental Hall	610.8	349.6	504.6	984.7	905.1	0.0	0.0	**3 354.8**
Total	**2 329.8**	**1 608.5**	**2 341.1**	**2 253.5**	**993.6**	**700.0**	**700.0**	**10 926.5**

Condensed Matter Physics

JINR has a unique base for experimental research (the IBR-2 pulse reactor and the DRIBs-III accelerator complex) allowing its scientists to conduct basic and applied research in the field of the physics of condensed state of matter and in adjacent areas — biology, medicine, materials science, etc., aimed at studying the structure and properties of nanosystems and new materials, biological objects, and biotechnologies.

I. Neutron scattering research methods

Neutron scattering research methods make it possible to obtain comprehensive information on the atomic and magnetic structure and dynamics of materials at the atomic and sub-atomic levels. Due to the peculiarities of interaction of slow neutrons with matter, neutron scattering is the most powerful technique to locate light atoms among heavy ones, to study the distribution of elements with close atomic numbers, and to investigate isotope substitution processes and magnetic structures.

Expected results and realization periods:

1. Physics and chemistry of novel functional materials

1.1. Determination of the parameters of atomic and magnetic structure of bulk and nanostructured functional materials demonstrating interesting physical phenomena and prospective for technological applications in a wide range of thermodynamic parameters; determination of the influence of structure parameters and cluster formation on physical properties — 2017–2023.

1.2. Determination of microscopic mechanisms giving rise to the magneto-electric effect in complex multiferroic oxides — 2019–2023.

1.3. Determination of the parameters of crystal and magnetic structures of new forms of simple transition metal oxides formed under extreme conditions — 2017–2021.

1.4. Determination of the effect of electrode microstructure on charging/ discharging processes in compact electric current sources — 2017–2021.

1.5. Determination of atomic structure and vibrational spectra of molecular complexes: ionic-molecular inclusive materials and complexes with electric charge transfer, structural and dynamical parameters of hydrogen bonding in bioactive materials — 2017–2019.

2. Physics of nanosystems and nanoscale phenomena

2.1. Clarification of proximity effects in magnetic layered nanostructures and analysis of their magnetic properties in permanent and varied magnetic fields — 2017–2019.

2.2. Determination of the structure of a number of promising nanosystems on the basis of composite carbon and silicon-containing materials including those based on fullerenes, nanodiamonds and their bioactive derivatives — 2017–2021.

2.3. Study of nanosystems by the positron annihilation spectroscopy (PAS) method. The PAS method of material study allows detailed information to be obtained about the atomic structure of materials at the atomic and subatomic levels. The main area of research is diagnostics of defects (vacancies and dislocations) in the surface layers, to a depth of about 1–20 mg/cm^2 (1 to 25 microns in iron), in metals, alloys, polymers, semiconductor, carbon and other materials. The PAS set-up, developed at JINR using a unique source of monochromatic positrons, allows one to obtain the distribution of defects over the sample's depth and (in one of the method versions) to distinguish between types of defects. The main application of the PAS method is to study near-surface layers of materials — metals and semiconductors, in which various ions are implanted and which alters the properties of these materials. This relates, in particular, to materials modified by the implantation of heavy ions or subjected to ion or neutron irradiation. Such studies open up the possibility of experimental study of the mechanism of radiation damage of materials, which is practically important for structural materials in atomic power engineering, semiconductor components in microelectronics (including space vehicles), etc. The studies by PAS of porous materials are of special interest because this method is one of the few allowing one to detect pores with dimensions of the order of a few nanometers. Such studies open new opportunities associated with the study of new polymeric materials and membranes, as well as technologies for the development of chemical catalysts.

2.4. Structural diagnostics and "in-operando" studies of physical process at electrochemical interfaces — 2017–2020.

3. Physics and chemistry of complex fluids and polymers

3.1. Comparative analysis of structural aspects of stabilization of disperse systems and complex liquids including biorelevant systems with nonmagnetic and magnetic nanoparticles in the bulk and at the interfaces — 2017–2023.

3.2. Determination of structural characteristics of magnetic elastomers and carbosilane dendrimers holding promise for technological applications — 2017–2019.

4. Molecular biology and pharmacology

4.1. Determination of structural characteristics of lipid nanosystems modeling the upper skin layer of humans and mammal animals to study the transport of pharmacological drugs through the skin. Determination of the phospholipid transport nanosystem morphology — 2017–2021.

4.2. Determination of structural and functional characteristics of biological nanosystems: protein macromolecules, DNA, RNA and their complexes — 2019–2023.

4.3. Analysis of structural features of the interaction of nanoparticles and functional complexes on their basis with biological macromolecules in the bulk and at the interfaces, the effect of the structural and cluster stability of nanosystems on the biocompatibility of complex solutions — 2017–2020.

5. Materials science and engineering

5.1. Determination of residual stresses in engineering materials for nuclear reactors, industrial materials and products — composites, reinforced systems, metal ceramics, shape memory alloys — 2017–2023.

5.2. Determination of characteristics of the internal structure of meteorites and construction of 3D models of their main fractions — 2020–2023.

5.3. Analysis of metamorphic, geodynamic and evolution processes in the lithosphere using data about the texture of deep and near-surface rocks. Exploration of the seismic anisotropy origin — 2017–2021.

5.4. Development of the model of solid polycrystalline materials for prediction of their elastic, strength and thermal properties, taking texture, inclusions, pores and microcracks into account — 2021–2023.

II. Optical methods of research

In the past few years, the condensed matter investigations have been supplemented and enriched by Raman scattering spectroscopy and microscopy on the basis of modern confocal laser scanning microscope "CARS".

Research fields:

Raman spectroscopy and microscopy. Spectral and microscopic studies of membrane proteins, cells and organisms.

Upconversion luminescence. Investigation of structural and luminescence characteristics of nano-glass-ceramics.

Expected results:

1. Determination of the role of lipids and detergents in the crystallization of membrane proteins by Raman and CARS spectroscopy.

2. Creation of in meso membrane protein crystallization concept on the basis of Raman, CARS and SERS spectroscopy and microscopy.

3. Demonstration of the possibilities of enhanced Raman spectroscopy and microscopy (including 3D-visualization) in studying various cells and organisms.

4. Integration of Raman spectroscopy with atomic force microscopy (Raman AFM): spectroscopy/microscopy with a resolution of up to 10 nm.

5. Achievement of highly efficient conversion of infrared radiation to upconversion luminescence in nanoceramic matrices doped with ions of rare earth elements (Er, Eu, Pr, Tm, Yb, and others) and making recommendations on their practical application.

III. Applied research with heavy ions

Techniques combining exposure to heavy-ion beams and other physico-chemical interactions give unique possibilities for changing the properties of materials and for creating new functional structures. The main emphasis is put on the modification of materials at the nanometer scale and on the study of the effects produced by heavy ions in matter with the aim of revealing the fundamental mechanisms and of developing nanotechnology applications. They include the development of new types of track membranes and functional materials based on track membranes used in various fields of technology and medicine; the production of ultrapure isotopes and the study of the properties of practically important radionuclides; the upgrade of the FLNR experimental equipment for the production of isotopes and materials modification. Further progress requires a significant improvement of instrumentation, covering the entire range of equipment, beginning with accelerators and extending to modern high-precision instruments for the study of the micro- and nanostructural characteristics of matter. New specialized channels will be constructed at the DC-280 cyclotron and at the modernized accelerator U400R. The equipment park will be significantly augmented with modern analytical methods, including scanning electron microscopy, high-resolution transmission electron microscopy, atomic force microscopy, scanning probe tomography, X-ray photoelectron spectroscopy, energy dispersive and crystal diffraction X-ray spectroscopy and many other complementary techniques. Ion track technology approaches will be used in combination with new thin film, multilayer technologies and new promising materials (graphene, plasmonic materials). The fields of applications will be focused on the strategic areas such as energetics, safety, ecology and health.

Expected results:

1. Detailed study of heavy-ion-induced structural effects in materials aimed at understanding the fundamental mechanisms of ion-matter interaction and at applications of beams of accelerated ions in nanotechnology.

2. Investigation of the radiation resistance of materials irradiated with high energy multi-charged ions, including real-time testing of microelectronic components for space applications.

3. Synthesis of nanostructured materials and study of their optical, electrical and magnetic properties.

4. Development of next-generation functional track membranes and track-membrane-based advanced materials for optical, medical, biochemical and sensor applications.

5. Development of hybrid nanotechnologies, combining methods of ion track technology and coating, thin-layer, multi-layer composite and surface modification technologies.

6. Production of radioisotopes for nuclear medicine and radioecological studies with γ-quanta, α-particle, and heavy-ion beams.

7. Development of specialized ion beam leading lines for applied research at the new DC-280 and modernized U400R accelerators.

8. Development of the laboratory complex in the new FLNR Laboratory Building in cooperation with the International Innovation Centre of Nanotechnology (a joint project between JINR and Rosnano).

Financing schedule (k$)

	2017	2018	2019	2020	2021	2022	2023	Total
Materials, equipment	500.0	500.0	500.0	500.0	500.0	500.0	500.0	**3 500.0**

Radiobiological and astrobiological research

Radiobiological research in 2017–2023 will be focused on studying heavy-ion action mechanisms at the molecular, cellular, tissue, and organism levels of biological organization. Special attention will be given to experimental animals' central nervous system (CNS) disorders because CNS has to be considered as a critical system when evaluating the radiation exposure risk for the interplanetary mission crews.

Astrobiological research will be focused on the problem that is central for understanding the production of the prebiotic compounds underlying the formation of the living systems: what is primary in the origin of life, genetics or metabolism? The planned research will be aimed at the development of unified theoretical and experimental approaches allowing for a possible influence of the following factors on the phenomenon of the origin of life on Earth: energy, evolutional, protometabolic, and the primordial environment. The second field of the astrobiological research is the search for and study of microfossils in meteorites and early Precambrian terrestrial rocks using electron microscopy and nuclear physics methods.

The main fields of research:

1. Research on the mechanisms of the induction of molecular disorders of the DNA structure by heavy charged particles of different energies and their repair

1.1. Damage in the nuclei of individual cells will be studied and the fine structure of clustered DNA damage will be analysed.

1.2. The influence will be evaluated of the distributions of DNA damage of different types on cell repairability.

1.3. Mechanisms will be clarified and dynamics will be described of the protein recognition of DNA clustered damage and its subsequent repair.

2. Research on the regularities and formation mechanisms of gene and structure mutations in mammalian and human cells under exposure to heavy charged particles of different energies

2.1. Specifics will be studied of the mutagenic action of sparsely and densely ionizing radiations on mammalian and human cells.

2.2. The mutagenic action of radiations of different quality on prokaryote and eukaryote cells will be analysed and compared.

2.3. Genetic instability mechanisms of mammalian and human cells will be cleared up.

3. Research on mechanisms of damage and restoration of morphological and functional disorders in various parts of the central nervous system under the action of heavy charged particles of various energies

3.1. Morphological, cytological, neurochemical, molecular, and physiological disorders of the central nervous system structures will be studied.

3.2. Modifications of behavioral functions in irradiated animals will be studied.

3.3. In experiments on primates, the effect of radiations of different quality on operator's activity elements will be assessed.

3.4. The neurophysiological and neurochemical mechanisms underlying these processes will be studied.

4. Mathematical modeling of the effects of ionizing radiations with different LET at the molecular and cellular levels. Development and analysis of mathematical models of the molecular mechanisms of high-energy charged particle-induced disorders in the CNS structure and functions

4.1. Mathematical models describing radiation-induced damage repair will be developed.

4.2. Models will be improved that describe the stages of DNA damage induction by ionizing radiations of different quality

4.3. Models will be developed describing the action of radiation on CNS structures and functions — in particular, models of the disorder of signal transport, ion regulation and synapse functioning, gene expression and protein synthesis, and hippocampus-based neurogenesis.

5. Radiation research

5.1. Physical support of the radiobiological experiments at JINR's nuclear physics facilities will be continued.

5.2. The development of the NICA complex will be continued as regards the design and calculation of its biological shielding, prediction of the radiation conditions at the facility and its environment, evaluation of the induced radioactivity of the equipment, evaluation of staff radiation exposure, organization of radiation safety measures, and development of radiation monitoring systems.

5.3. As part of cooperation in nuclear planetary science with JINR's Frank Laboratory of Neutron Physics and the Institute of Space Research of the Russian Academy of Sciences, it is planned to study the performances of the instruments and to calibrate them using different planetary soil models at the already operational JINR-based DAN experimental stand.

6. Astrobiological research

6.1. A possibility will be studied of the self-assembly of 3',5'-cyclic nucleotides in the system "formamide + meteorite matter" under exposure to high-energy charged particles.

6.2. To study the mechanism of nucleoside synthesis reactions, sugars and nucleic bases that were obtained in earlier experiments by proton irradiation of formamide in the presence of meteorite matter will be irradiated with accelerated high-energy charged particles.

6.3. The synergy effect will be studied in biomolecule synthesis during irradiation of formamide in the presence of amino acids.

6.4. One-pot phosphorylation of nucleosides during proton irradiation of formamide in the presence of meteorite matter and inorganic phosphates will be studied.

6.5. A search for microfossils in meteorites and early Precambrian terrestrial rocks will be performed with the use of electronic microscopy.

6.6. Criteria will be formulated and techniques will be developed for the determination of the terrestrial microorganism contamination of meteorite matter samples to prevent false identification of the extraterrestrial origin of microorganisms.

6.7. The elemental composition of cosmic dust and other materials of extraterrestrial origin will be determined by multi-element neutron activation analysis at the IBR-2 reactor.

7. Molecular and radiobiological aspects of radiation therapy

7.1. Development of methods for increasing the radiosensitivity of tumor cells based on the combined action of photon and proton beams and inhibitors of DNA damage repair.

7.2. Investigation of the sensitivity of radioresistant tumor cells under the influence of the “radionuclide – vector molecule” complex and DNA damage repair inhibitors.

Theoretical Physics

The studies conducted at BLTP are interdisciplinary; they are directly integrated into international projects with the participation of scientists from major research centres in the world and are closely coordinated with the JINR experimental programmes. Intensive development of the research is planned in nuclear and particle astrophysics, Higgs boson phenomenology, hadron physics under extreme conditions (in connection with the experimental programme of the NICA/MPD project, and experiments at RHIC, LHC and FAIR), lattice QCD calculations. Studies in condensed matter physics will be more tightly correlated with practical problems in the field of nanotechnology for creation of new materials and electronic devices.

Quantum field theory and particle physics

Theoretical research in the field of particle physics will be emphasized on the support of physics programmes of major international collaborations with JINR's participation (LHC, RHIC, FAIR, etc.) and of those at the JINR basic facilities, primarily, of the NICA/MPD project. Major attention will be paid to the phenomenology of the Standard Model including studies of the Higgs boson, searches for new physics beyond the Standard Model, neutrino physics, hadron structure and spin physics, phase transitions in hot and dense hadronic matter, heavy flavor physics and hadron spectroscopy, the dark matter problem, and astrophysical aspects of elementary particle physics.

Nuclear theory

The first-priority direction in the area of low-energy nuclear physics will be studies of exotic and superheavy nuclei which is the goal of the experimental projects DRIBs III and the Factory of superheavy elements at JINR and all others megaprojects in Europe, the United States, China, and Japan. This demands that the corresponding theoretical studies be developed. Microscopic selfconsistent nuclear models owing to include, in the theoretical schemes, the anharmonic and fragmentation effects beyond the mean field approximation will be elaborated there. The models will be applied to analyse quantitatively the processes of nuclear fusion and fission and to predict 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. More attention will be given to cluster effects in the properties of exotic heavy nuclei and the mechanisms of transfer of nucleons, clusters and disintegration of a nucleus in the field of the other one. The mathematically rigorous and effective methods of the few-body theory will be developed and applied in studies of various quantum few-body systems, e.g. collisions of ultracold atoms and molecules in confined geometry of laser traps. Investigations of high-energy collisions of heavy ions will be performed in close connections with the NICA/MPD project aimed at revealing the most informative observables for experimentalists. In the framework of the advanced models the color degrees of freedom will be considered directly and the effect of the medium-modified quark-hadron interaction on the dilepton production will be investigated.

Theory of condensed matter

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. The electronic band structure, spectral properties of charge carrier quasiparticles, magnetic and charge collective excitations, metalinsulator and magnetic phase transitions, Cu- and Fe-based high-T_c superconductivity, charge and spin-orbital ordering will be studied. Research in this field will be aimed at supporting the experimental studies of these materials conducted at the Frank Laboratory of Neutron Physics. Investigations in the field of nanostructures and nanoscaled phenomena will be addressed to a study of physical characteristics of nanomaterials promising for various applications in modern nanotechnologies. The problem of quantum transport in carbon-based and molecular devices as well as the resonance tunneling phenomena in various heterostructures and the layered superconductors will be investigated. 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.

Modern mathematical physics

Superstring theory, the most serious and worldwide pursued candidate for the unification of all fundamental interactions including quantum gravity, will be the central topic in mathematical physics studies at BLTP. 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, the models of particles and superparticles, as well as new versions of the supersymmetric quantum mechanics, including models based on semi-simple super groups will be studied. To apply and develop new ideas generated with the string theory, it is crucial to use mathematical methods of the theory of integrated systems, quantum groups and non-commutative geometry, superfield methods, including the method of harmonic superspaces.

Research and education project DIAS-TH

The general objective of the continuously running BLTP project “Dubna International School of Theoretical Physics (DIAS-TH)” will be the promotion of scientific and educational programmes at JINR. The unique feature of DIAS-TH is its coherent integration into the scientific life of BLTP, which will ensure regular and natural participation of the leading scientists in education and training activities. Cooperation of DIAS-TH with international and Russian foundations (UNESCO, DAAD, DFG, RFBR, etc.) and state organizations (BMBF, INFN, CNRS) is very important for the successful implementation of this project.

Information Technology

Development of the computing infrastructure

The aim of the further development of the JINR computing infrastructure is to provide performance of a whole range of competitive research activities at the world's level at JINR and cooperating centres worldwide both within the JINR programme for scientific research and development, in particular the NICA megaproject, and within the priority research tasks that are performed in cooperation with leading research centres such as CERN, FAIR, BNL, etc.

For the Laboratory of Information Technology, one of the major objectives in the Seven-year plan is the creation of a unified information environment integrating a number of various technological solutions, concepts and techniques. Such environment should integrate supercomputer (heterogeneous), grid- and cloud-complexes and systems in order to grant optimal approaches for solving various types of scientific and applied tasks. The necessary requirements to such an environment are scalability, interoperability, and adaptability to new technical solutions.

Expected results:

1. Creation of a JINR Multifunctional Information and Computing Complex (MICC) of a global level for the development of advanced information technology;
2. Development of a territorially distributed research environment to provide the use of the Complex capacities by the JINR and cooperating centres worldwide including joint international projects;
3. Research in the field of intensive operations with mass data in the distributed systems (Big Data), development of corresponding tools and methods of visualization, including 3D;
4. Scientific studies in the field of integrating base, cloud, grid and high-performance computing technologies with the purpose of their optimal use within the MICC;
5. Research on issues of optimizing the processes of using the existing capacities, in particular supercomputers, for data processing in distributed environment;
6. Introduction and development of a methodology of a short-term/medium term/long-term forecast of the MICC development;
7. Research in the field of integration of heterogeneous computing resources and data sources into a unified distributed computing system;
8. Creation of a software technological complex providing introduction of cloud technologies for organization of research by distributed user groups, introduction of intellectual methods of new generation grid-cloud structures management;
9. Research in the field of the global monitoring of the distributed computing systems;
10. Development of new parallel applications, cross-platform and multi-algorithm software complexes in a heterogeneous computing environment that allow one to expand a spectrum of computationally intensive solved fundamental scientific problems.
11. Development of a unified analytical system for managing MICC resources and data streams to increase the efficiency of using computing resources and storage resources and simplify the process of processing data from new experiments.
12. Development of a hyper-converged platform, including the “Govorun” supercomputer as a satellite project in the general infrastructure project of MICC, in terms of increasing computing resources and in terms of developing services deployed on the platform, determined by the needs of users, including the needs of the NICA megaproject and the neutrino program, for significant acceleration of ongoing research based on the paradigm of heterogeneous computing.
13. Creation of a multilevel data storage (“data lake”) of JINR to provide a constantly expanding resource for long-term information storage, the volume and speed of which is balanced with the corresponding information flows.

One of the main components of the Multifunctional Information and Computing Centre providing access to the resources and opportunity of work with Big Data is the network infrastructure.

For this infrastructure and its telecommunication data links to correspond to the requirements on reliability and availability of the complex for the JINR and cooperating centres worldwide using the resources of the complex to perform their investigations, the obligatory double reservation of all the connections and reliable 100 Gbps and more telecommunication channels are required.

A major task of the Seven-year plan will be further extension of the engineering infrastructure of the MICC connected with the start-up of the NICA accelerator complex and conduct of its experiments.

One of the most demanded and ambitious tasks, which should be implemented within the framework of the seven-year development plan of JINR, is the development of the JINR corporative information system for collective use and management of the information produced by JINR laboratories and departments to establishing of the general information space, improvement of information provision and decision-making process support. JINR plans to develop a digital model of an international research center, a replicable information platform that allows automating and digitizing administrative processes to ensure the maximum efficiency of the main activities of a scientific centre.

Mathematical support of studies conducted at JINR

The solution of problems in computational physics and mathematics, encompassing a wide spectrum of research underway at JINR, requires the development of new mathematical methods and approaches, the creation of algorithms and software for numerical and symbolic-numerical simulations with the help of the newest computer hardware with multi-core architecture, coprocessors and graphic accelerators. Such computational systems provide the way towards significant speed-up of mathematical calculations by selecting the paralleling technology which takes into account the specificity of the problem under solution. The adaptation to the heterogeneous architectures of previously developed software and the creation of new applications based on modern parallelization techniques making the best use of the opportunities provided by the available computing resources are of particular importance. A separate task is the development of software platforms and environments for designing parallel applications and development of services that will significantly simplify the user work on such computing complexes.

Expected results:

1. Software development and realization of mathematical support of experiments conducted at the JINR basic facilities and in frames of international collaborations at the largest installations worldwide, including introduction of high-speed methods, algorithms and software for parallel processing and analysis of experimental data on heterogeneous and distributed computer complexes;
2. Development of numerical methods, algorithms and software complexes for modelling complex physical systems, including interactions inside a hot and dense nuclear matter, physico-chemical processes in materials exposed to heavy ions, evolution of localized nanostructures in the open dissipative systems, properties of atoms in magnetic optical traps, electromagnetic response of nanoparticles and optical properties of nanomaterials, evolution of quantum systems in external fields, astrophysical studies;
3. Development of methods and algorithms of computer algebra for simulation and research of quantum computations and information processes, low-dimensional nanostructures in external fields, discrete quantum systems with nontrivial symmetries.
4. Development of mathematical, algorithmic and program methods of description of tangled (entanglement of) conditions of qubit systems as a basic resource of quantum informatics.
5. Development of symbol-numerical methods, algorithms and software complexes for the analysis of low-dimensional compound quantum systems in molecular, atomic and nuclear physics.
6. Development of algorithms based on recurrent and convolutional neural networks for ML/DL problems and big data analysis, which are primarily intended to accelerate the recognition of multiple tracks in particle physics experiments, including for the NICA megaproject and the needs of neutrino experiments.

Plan for the development of the Multifunctional Information and Computing Complex

	2017	2018	2019	2020	2021	2022	2023
Tier1-CMS and NICA data storage							
Performance upgrade: CPU kHS06	67.2	83.2	160.0	200.0	240.0	300.0	350.0
Disk storage upgrade (TB)	5 070	6 100	8 000	8 800	10 800	13 100	16 100
Mass memory upgrade (TB)	20 000	20 000	20 000	25 000	30 000	35 000	42 000
Tier2 and computer resources with a storage system for local users							
Performance upgrade: CPU kHS06	59.2	75.2	96.0	110.0	130.0	150.0	170.0
Upgrade of disk storage (TB)	2 970	3 400	5 000	5 500	6 000	6 500	7 000
Heterogeneous cluster for parallel computations							
Performance (Tflops)	180	240	300	360	420	480	540
Upgrade of disk storage (TB)	55	60	60	65	70	75	80
Cloud infrastructure							
Cores	630	1 000	1 500	2 250	3 500	5 000	7 500
RAM (GB)	1 280	2 000	3 000	4 500	7 000	10 000	15 000
Disk servers (TB)	40	80	160	320	640	1 200	2 500
External telecommunication data links and JINR local area network							
Data link bandwidth (Gbps)	100						

Financing schedule (k$)

Name of works	2017	2018	2019	2020	2021	2022	2023
Section I							
Phased modernization of the climate control system, fire extinguishing system and uninterruptible power supplies (UPS)	404.3	794.9	1454.7	697.8	666.3	521.2	507.3
Gradual increase in computing resources	653.0	1 603.2	690.0	1 578.0	839.4	907.8	870.4
Phased expansion of the storage system on disk servers	433.2	1 593.3	119.9	1 365.1	1 177.6	1 199.2	1 399.3
Robotic Tape Storage Gradual Capacity Expansion	263.8	0.0	0.0	0.0	0.0	0.0	0.0
Step-by-step build-up of local network infrastructure	377.6	0.0	0.0	0.0	0.0	0.0	0.0
Extending computing resources and disk arrays of a heterogeneous cluster (HybriLIT platform)	41.7	116.9	48.4	151.6	150.0	361.3	412.5
Supercomputer “Govorun”	2 495.0	194.6	2 537.6	0.0	0.0	0.0	0.0
Cloud infrastructure development	172.1	0.0	0.0	176.3	110.0	110.5	110.5
Diesel generator set (DGS)	440.4	412.2	0.0	0.0	0.0	0.0	0.0
Replacement of transformers	327.3	0.0	0.0	0.0	0.0	0.0	0.0
Total for Section I	**5 608.4**	**4 715.1**	**4 850.6**	**3 968.8**	**2 943.3**	**3 100.0**	**3 300.0**
Section II							
Step-by-step build-up of local network infrastructure	0.0	1 272.7	682.5	390.3	25.7	0.0	0.0
Robotic tape storage incremental capacity expansion	0.0	0.0	1320.0	0.0	145.5	148.3	149.7
Consumables, equipment and specialized licensed software	281.0	230.7	192.5	43.1	220.1	121.2	120.3
Replacement of critical and obsolete equipment	301.7	294.4	965.7	139.2	0.0	88.0	280.1
Equipment for the central core of the network infrastructure	282.9	193.2	201.5	0.0	234.4	122.3	330.2
Modernization of equipment for external communication channels and transition to 100 Gbps	180.0	340.2	260.1	52.7	0.0	200.0	0.0
Diesel generator set (DGS)	0.0	0.0	18.2	87.0	20.0	20.2	19.7
Modernization of the 2nd and 4th floors	0.0	0.0	0.0	0.0	12.7	0.0	0.0
Total for Section II	**1 045.6**	**2 331.2**	**3 640.5**	**712.3**	**658.4**	**700.0**	**900.0**
Total	**6 654.0**	**7 046.3**	**8 491.1**	**4 681.1**	**3 601.7**	**3 800.0**	**4 200.0**
Licensed software	233.6	228.0	203.8	201.1	200.0	150.0	250.0

Education

Being an international research organization, JINR has a great potential for education and training in the disciplines coinciding with the Institute's main directions of research. While providing a formal education, like that of a university, is not a purpose of the Institute, graduate and postgraduate students from the Member States can join the various research groups of JINR Laboratories to be trained in physics, engineering, computer science and other fields. It is the responsibility of the University Centre of JINR to ensure the effective use of JINR's facilities and expertise for education of highly qualified research scientists and engineers from the Member States. To implement this mission, UC shall pursue the following activities in the next seven years.

The first priority of UC remains the delivery of a high-quality service to the students from the Member States, who arrive at JINR Laboratories to prepare their BSc, MSc and PhD theses. UC takes care of their reception and accommodation and provides the necessary assistance during their stay in Dubna. Selected lecture courses are organized by UC in accordance with the curricula of the mother universities provided a mutual agreement on this matter between JINR and the university is concluded. Needless to say that the effective work in this direction is not possible without close collaboration and partnership with high schools, universities and research centres of the Member States. During the next seven years, UC will take efforts to further strengthen its relations with these scientific and educational institutions.

An important task of UC is to organize educational summer activities for undergraduate students. These include both a series of short-term (International Student Practice) and long-term (Summer Student Programme) stays of student groups from the Member States aimed at their joining the day-to-day work of research teams in JINR Laboratories. Visits to the accelerators and experimental areas are also part of these activities. It is an excellent opportunity to get familiar with the JINR environment and to make valuable contacts with other students and scientists. Having participated in the summer activities, many of the students return to the Institute to work on their MSc and PhD theses. In the coming years these activities will be continued and extended and more efforts to develop the optimal organization and contents of these programmes will be made.

An emerging activity of UC is the practical training in nuclear physics and accelerator technology for students and young scientists from the Member States. A series of training courses in the various fields from radiation protection, safety and basics of nuclear physics to particle detector physics, RF and vacuum technology, beam diagnostics and automation are being prepared. The ultimate goal is to extend the training to use dedicated beam lines of the linear electron accelerator with an energy of up to several hundred MeV, which is being constructed in Building 118 to provide test beams to the JINR Laboratories. The practical training will allow the students and young researchers to improve the existing and to obtain new knowledge and skills in modern hardware and technology not only by learning about it from books and lectures, but also via personal hands-on experience. While some courses have existed since 2016, during the next seven years this practical training is planned to be fully deployed and become operational. It is equally important to ensure its permanent upgrade to keep the courses up to the overall progress of the technology in the world.

The outreach programmes of JINR aimed at school children and teachers from the Member States is an important part of the activity of the University Centre, which has already gained a very successful experience of interaction with these communities. Various events intended to bring the modern understanding of the nature and highlights of JINR achievements to the schools and colleges of the Member States remain a priority task for UC in the upcoming period of work.

Besides teaching and supervision of graduate and postgraduate students, UC is responsible for the academic and technical training of JINR personnel. Among others, this activity includes regular industrial safety courses governed by Rostekhnadzor (Russian Federal Service for Ecological, Technological and Nuclear Supervision) according to the relevant regulations of the Russian Federation.

Since 2016, UC has been running the funds intended for the Association of Young Scientists and Specialists of JINR (AYSS), including annual grants for young specialists and scientists, regular international conferences and schools for youth organized by AYSS, sports and other social activities.

Development of the Engineering Infrastructure

The engineering infrastructure of JINR includes a supply system of energy resources like electricity, heat, cold and hot water, liquid nitrogen; cooling and sewage systems, communication and telecommunication systems and safety system.

1. Supply of energy resources

Electricity

The main issue in the development of the JINR power supply system for the next seven years is the reconstruction of GPP-1 and GPP-2 with a capacity of 28 MW. The terms of reconstruction of GPP-1 and GPP-2 are 2021 and 2023 respectively.

The reconstruction of GPP-2 consists in launching the 3rd and 4th transformers, which will allow sorting out the basic JINR facilities into separate groups: IBR-2, U400, U400M, Phasotron, local network and computing clusters. This will considerably decrease the risk of hazardous failure of these facilities due to general city problems.

The reconstruction of GPP-1 within the 3rd transformer will increase the JINR power supply and provide trouble-free operation of the FLNR and VBLHEP laboratories, including the NICA project.

To obtain additional 4 MW power supply from the Moscow Canal in order to increase the reliability of the system, one needs to reconstruct the 3rd and 4th feeders connected to GPP-2, which is financed from Russian tax service funds.

The provision of stand-by electric supplies is also very important. It will be implemented by installing autonomous generators on the sites that are vitally important to the Institute. It is crucial to the telephone station, JINR's safety system, water and sewage systems.

Heat

Working plans for 2017–2023:

- to automate the Eastern heat station;
- to reconstruct and replace the city heat networks;
- to reconstruct and replace the JINR heat networks;
- to replace the outdated commercial accounting blocks at the Central and Eastern heat stations (2017);
- to install modern equipment to organize heat accounting system on the main heat networks and large objects, with automate processing data at the united control station;
- to adjust the heat networks in JINR and the city.

Water and sewage

The main problem of these systems is the networks wear, namely water network, which has been in use for more than 50 years and is outdated. It needs planed replacement with modern technological tubes.

Working plans to provide better conditions for water supply:

- to automate the potable water production at the pump-filter station;
- to install a water accounting system at the pump-filter station;
- to reconstruct and replace the JINR and city water networks.

2. Communication and telecommunication means

Telephone communications

Reconstruction of the JINR digital telephone station is near completion. It has 5600 subscribers with a possibility of increasing capacity at VBLHEP up to 1200 subscribers and more for NICA project needs.

For the reliability of the system, one needs to reconstruct and replace the fiber-optic line channels and local cable network at JINR and city, going to a high-level provider.

Local area emergency alarm system

The JINR local area emergency alarm system should provide alarm signals and information to the leaders and object staff, local population residing within the system local area, and other emergency services and organizations in a 5 km area of nuclear- and radiation-hazardous objects. JINR's modern local area emergency alarm system interconnected with the city's alarm systems is planned to be in use in 2023.

Modern control systems

It is planned to build a unified JINR CCTV system and to develop the present system of automated processing of data of energy resources at the unified control station, which already includes more than 500 accounting blocks.

3. Safety

Labor protection, industrial safety, management of natural resources

To address the tasks in labor protection and industrial safety within the development of the JINR engineering infrastructure in accordance with the federal laws, standards and regulations, the following is planned:

- special assessment of working places for labor conditions;
- replacement on scheduled basis of outdated equipment;
- modernization of the Industrial-Sanitary Laboratory equipment;
- improvement of informational and technical support of staff;
- reviews of performance and professional development of JINR leaders and specialists/

Radiation and nuclear safety

JINR's efficient policy is aimed at minimizing the radiation effect on humans and the environment and comprises provision of increased safety of the operating and planned nuclear physics facilities and provision of safety in handling nuclear materials and radioactive substances.

Working plans of the Radiation Safety Department for 2017–2023:

– to further develop the existing system of the individual dosimetry control at the JINR nuclear physics facilities, its adaptation to the real irradiation fields with corresponding correction coefficients;

– to upgrade the existing radiation control systems of the operating facilities, to elaborate new systems on the planned radiation-hazardous sites of JINR; to develop a high-energy neutron control system; to replace obsolete equipment;

- to transmit for recycle the outdated radioactive substances to prevent their accumulation;
- to supply radiation control metrological devices by own and third-party centres;

– to obtain accreditation for the metrological services and radiation control laboratory;

– to obtain permission of the Rostechnadzor (Russian Technical Supervisory Authority) for the atmospheric discharge of radioactive substances.

Working plans of the Radioactive Substances and Nuclear Materials Department for 2017–2023:

– to purchase the necessary materials and equipment;

– to prolong the usage of nuclear materials and radioactive substances storage;

– to develop an automatic system of radiation control for the JINR central storage;

– to provide licensing and metrology for nuclear materials and radioactive substances accounting and control;

– to adjust the accounting and control system including computer data base;

– to continuously improve the knowledge by the leaders and staff of the accounting and control system in accordance with standards and regulations;

– to set up a control and methodology group for radiation control, measurements and documentation improvement.

Within the framework of the current seven-year period, it is planned to create the JINR Emergency Technical Center in 2022.

Fire security

It is planned to conduct a stage-by-stage upgrade of the operating systems of automatic fire alarm and fire-fighting, as well as to launch new modern systems involving in the process the specialists from the JINR station of automatic firefighting equipment. For costs optimizations, one should develop a complex of modern systems, which will unify the functions of fire alarm systems and object safety systems. In 2017, the target program "Ensuring fire safety at JINR for 2017–2023" was approved, within the framework of which specialized systems and equipment are being modernized.

The regular checks show the inconsistency of the JINR objects to actual fire security laws, standards and regulations. According to the proposed system approach of JINR accreditations within all licensing fire protection works, it is planned to improve and maintain the proper level of the fire security on the Institute's sites.

Financing schedule (k$)

Budget items	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**Total**
Engineering support and labor safety (infrastructure)	**26.0**	**29.5**	**36.5**	**31.9**	**44.2**	**45.6**	**49.5**	**263.2**
conducting a special assessment of working conditions	1.2	0.6	3.4	3.1	1.0	1.1	1.2	**11.6**
- *infrastructure*	0.0	0.1	0.2	0.3	0.1	0.1	0.1	**0.9**
- *laboratory budget* *	1.2	0.5	3.2	2.8	0.9	1.0	1.1	**10.7**
Industrial Safety	12.0	14.8	15.2	16.3	18.4	19.5	20.4	**116.6**
- *infrastructure*	1.5	1.2	4.5	1.3	1.3	1.5	2.0	**13.3**
- *laboratory budget**	10.5	13.6	10.7	15.0	17.1	18.0	18.4	**103.3**
Overhaul and maintenance of buildings, structures, equipment	**7.9**	**3.8**	**6.0**	**11.1**	**51.0**	**15.5**	**15.6**	**110.9**
repair of buildings and structures	2.1	2.2	2.3	2.5	2.7	2.8	2.9	**17.5**
modernization of automatic telephone exchange-6	0.5	0.3	0.5	0.2	0.3	0.3	0.3	**2.4**

replacement of low-current cable lines	1.3	1.3	3.2	8.4	18.0	2.5	2.5	**37.2**
replacement of main water supply networks of DLNP	1.6	3.3	6.0	1.6	10.0	5.2	5.2	**32.9**
- infrastructure	0.0	0.0	0.0	0.0	10.0	5.2	5.2	**20.4**
*- laboratory budget **	1.6	3.3	6.0	1.6	0.0	0.0	0.0	**12.5**
replacement of main heating networks of DLNP	1.9	7.2	1.4	9.3	20.0	4.7	4.7	**49.2**
- infrastructure	0.0	0.0	0.0	0.0	20.0	4.7	4.7	**29.4**
*- laboratory budget **	1.9	7.2	1.4	9.3	0.0	0.0	0.0	**19.8**
replacement of street lighting DLNP	4.0	0.0	0.0	0.0	0.0	0.0	0.0	**4.0**
Construction of buildings and technological systems	**0.0**	**12.2**	**41.9**	**137.2**	**544.9**	**326.9**	**358.3**	**1 421.4**
dispatching and video surveillance system	3.0	0.5	0.7	2.3	1.5	2.0	2.0	**12.0**
- infrastructure	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
*- laboratory budget **	3.0	0.5	0.7	2.3	1.5	2.0	2.0	**12.0**
reconstruction of the GPP	0.0	12.2	24.8	88.5	467.0	302.0	358.0	**1 252.5**
local warning system	0.0	0.0	0.0	4.0	1.7	0.3	0.3	**6.3**
JINR emergency technical center	0.0	0.0	9.9	26.6	40.0	15.6	0.0	**92.1**
JINR geosystem	0.0	0.0	0.0	0.0	7.0	9.0	0.0	**16.0**
building 133 (modernization of the ORDV storage facility and the ITSO complex)	0.0	0.0	7.2	18.1	12.0	0.0	0.0	**37.3**
reconstruction of highly hazardous facilities and documentation to extend the life of nuclear facilities	0.0	0.0	23.4	21.0	33.6	0.0	0.0	**78.0**
- infrastructure	0.0	0.0	0.0	0.0	5.2	0.0	0.0	**5.2**
*- laboratory budget **	0.0	0.0	23.4	21.0	28.4	0.0	0.0	**72.8**
pumping and filtering station of the second stage of construction	0.0	0.0	0.0	0.0	12.0	0.0	0.0	**12.0**
Total **	**33.9**	**45.5**	**84.4**	**180.2**	**640.1**	**388.0**	**423.4**	**1 795.5**
* funded from laboratory budgets	18.2	25.1	45.4	52.0	47.9	21.0	21.5	**231.1**
** funded from the JINR infrastructure					**GPP-2**	302.0	358.0	**660.0**

Innovation Activities

The strategic goal of the innovative development of JINR for the period up to 2030 is to make the Institute the leading center for the transfer of knowledge of the JINR member countries in the field of nuclear physics and accelerators. Implementation of innovation plans for the period 2021–2023 assumes concentration of efforts in the following main directions. Technology transfer and commercialization.

I. Establishment of an international innovation center for nuclear physics research

The main goals of organizing the JINR Interlaboratory Innovation Center (hereinafter referred to as the Innovation Center) are to conduct innovative research in the most demanded areas of radiation, biomedical technologies, in particular, the development of technologies and methods in the field of nuclear and radiation medicine, radiation materials science, as well as ecology and information systems, personnel training and advanced training of specialists from the JINR member states in radiation biology and medical physics.

The main stages of the implementation of the project for the creation of the Innovation Center are:

– applied innovative research within the framework of the project of a complex of superconducting rings on colliding beams of heavy ions NICA, including the creation of three specialized research channels: (1) heavy charged high-energy particles (150–350 MeV/nucleon for research on the radiation resistance of semiconductor micro- and nano electronics and also 400–800 MeV/nucleon for radiobiological research and modeling the effects of heavy charged particles of Galactic cosmic radiation on biological objects, including the cognitive functions of the brain of small laboratory animals and primates); (2) low-energy heavy charged particles with an energy of 3.2 MeV/nucleon for testing the radiation resistance of micro- and nano-electronics; (3) beams of protons, deuterons and light ions with energies of 1.0–4.5 GeV/nucleon for obtaining new nuclear data for nuclear power technologies, transmutation of spent nuclear fuel, creation of new neutron sources; (implementation period: 2021–2024);

– development in the Veksler and Baldin Laboratory of High Energy Physics of high-temperature superconductivity technologies, first of all, for the creation of electromagnets of accelerators and inductive energy storage;

– establishment in the Flerov Laboratory of Nuclear Reactions of the DC-140 accelerator complex for research in the field of radiation materials science, tests for radiation resistance of electronic components, improvement of the technology for the production of track membranes, etc. (implementation period: 2021–2023);

– establishment in the Flerov Laboratory of Nuclear Reactions of a modern radiochemical complex, including a class I radiochemical laboratory, with the aim of developing new radioisotopes for nuclear medicine in photonuclear reactions at an industrial electron accelerator (implementation period: 2022–2026);

– radiation biology: expansion of the research infrastructure of the Laboratory of Radiation Biology, development of OMICS technologies, neuroradiobiological research, development of approaches to improve the effectiveness of radiation therapy based on radiomodifiers (pharmaceuticals, transgenic systems), search for new methods of targeted delivery (molecular vectors) of radiomodifiers and radionuclides to tumor cells;

– establishment of a center for research and development in the field of radiation therapy: research on proton flash therapy, development of new approaches to treatment planning; pencil beam technologies, creation of a superconducting proton cyclotron (230 MeV) as a pilot facility for a future medical center (implementation period: 2021–2024).

The Innovation Center program will also include medium-term interlaboratory projects that imply the expansion of the experimental research program, as a place for the development of new technologies and a testing ground for advanced scientific research (Open Research Space @ DUBNA) in the following areas: life sciences, technologies of environmentally friendly carbon-free energy, big data and quantum computing. In addition to these new directions, the development of the directions already implemented at JINR in the field of artificial intelligence and quantum computing technologies will be carried out on the basis of the Meshcheryakov Laboratory of Information Technologies and the Veksler and Baldin Laboratory of High Energy Physics, R&D on linear superconducting continuous accelerators; micropixel detectors of the Medipix family, new avalanche photodetectors, laser metrology, laser inclinometers, etc.

For the implementation of the main stages of the project to create the Innovation Center a roadmap should be developed.

The implementation of innovative projects based on the research infrastructure of the Innovation Center should become a significant additional incentive to expand the interest and involvement of the participating countries and associate members in the JINR research program. The priority area for the development of the Innovation Center should be to provide opportunities for young professionals and students from the participating countries to carry out cutting-edge innovative research.

II. Effective integration into the global innovation system

One of the important tasks of the current seven-year period is the effective integration of JINR into the global innovation system and into the global scientific information system. In this direction, the Institute plans to carry out activities on the following main tasks.

1. Development of partnerships in the field of innovation with organizations of the European Union, including the European association "Knowledge4Innovation", the European Institute of Innovation and Technology (EIT).

2. Formation of the leading positions of JINR in expert scientific and innovation communities and committees of interstate integration associations, including the JINR member countries, CIS member states, EAEU, BRICS, etc.

3. Conducting field events in the JINR Member States in order to promote the innovative capabilities of the Institute and form communication channels in the field of innovation.

4. Organization of internships at JINR and innovation centers on the territory of the Russian Federation for students and young employees of research, educational and innovative organizations from the JINR member countries.

5. Participation in international exhibitions, conferences, forums of an innovative nature.

Specific activities and deadlines for completing the tasks of this section of the program for 2017–2023 depends on various factors, so they will be updated annually in the plans of JINR innovation activities.

III. Information support and PR for innovation activities at JINR

Noting the importance of broad coverage of JINR's innovative activities, one of the priority tasks should be:

– development, professional content and promotion of the site for innovative research at JINR;

– implementation of the best practices for promoting innovations, cooperation and use of the experience of the CERN technology transfer group;

– preparation and placement of popular scientific articles, digests about the innovative potential of JINR;

– participation in international exhibitions, conferences, innovation forums;

– participation in JINR offsite events in the participating countries in order to present the innovative potential of the Institute.

The innovative activities of JINR should also stimulate the participating countries to expand the experimental research agenda at all basic JINR facilities, serve as a testing ground for the development and mastering of new technologies, and contribute to the creation of research infrastructure in the JINR Member States and other interested countries.

Particular attention should be paid to improving the activities of existing and creating new subjects of management and coordination of innovation activities, including expanding the functionality of the JINR Expert Council on Innovations by including in it representatives of the state structures of the JINR Member States responsible for innovative development.

With the aim of additional support for the development of the most promising innovative directions, the issue of establishing a grant from the Directorate, a competition for innovative projects, and the JINR Innovation Development Fund is being considered.

Particular attention should be paid to the issues of registration and commercialization of the institute's rights to the results of intellectual activity, the development of new approaches to organizing work with intellectual property at the institute.

In order to create a system for processing business requests for custom R&D, it is planned to expand interaction with companies-residents of the special economic zone of the technology-innovative type “Dubna”.

Monitoring the implementation of seven-year plan and long-term development strategy of JINR

Strategic Plan for the Long-Term Development of JINR for the period up to 2030 and beyond, presented in November 2020, defines the principles for the formation of the next medium-term plans for the development of JINR. The JINR Strategy formulates a system of performance indicators for the Institute and provides for its application for monitoring its activities. The system of indicators and monitoring are a key tool for analyzing the progress of solving the tasks formulated in the current seven-year development plan and assessing the effectiveness of JINR's work in key areas of activity, and ensuring the compliance of the scientific, scientific, educational and innovative activities of the Institute with the most modern international standards, and its demand by the JINR Member States.

The scorecard consists of two groups of criteria. The first group characterizes the level of the Institute's ability to perceive, accumulate and produce scientific knowledge, develop research infrastructure, including virtual infrastructure, and strengthen the Institute's status as an international intergovernmental organization. The second group characterizes the current performance in the main areas of the Institute's activities: research and development of research infrastructure, technology creation, scientific and educational activities for the training of highly qualified personnel for the member states and partners of the Institute, exchange of scientific and technical information.

Each of these two groups contains the main indicators (top-level indicators) of three main types related to research and research infrastructure, the characterization of the Institute as an international intergovernmental organization, human resources and the current state of staff.

Monitoring of the main indicators is provided by the indicators of the lower level, a detailed system of characteristics, parameters and indicators, approved upon adoption of the next seven-year plan for the development of JINR and adjusted on an annual basis. The system of indicators and monitoring will be applied starting from 2022.

Human Resources and Social Policy

The Seven-year plan of the development of JINR for 2017–2023 is aimed at providing effective organization of work of the Institute's personnel, improvement of the system of assessment and remuneration of labour of the scientific researchers and other categories of the JINR staff, attraction of young scientific, engineering, and administrative personnel, and social protection of the staff. The Plan includes the following activities:

I. Human resources

1. Active involvement of scientists, heads and experts from the Member States of JINR for broader participation in work of JINR scientific, administrative and engineering sectors.
2. Creation of conditions for the attraction of high-potential scientists and experts from a broad range of countries including those that are not Member States of JINR for work at JINR on a competitive basis (associated personnel).
3. Realization of a package of measures for the attraction of young people, their training and permanent recruitment in the JINR staff on the basis of further development of the system of material and social support of youth, of the education system, of the creation of conditions for professional growth, increase of motivation to scientific and technical, and organizational and administrative activities.
4. Formation of a personnel reserve for vacancy filling of superior positions in the scientific, administrative and engineering sectors of JINR.
5. Creation of an effective system of professional development of the JINR staff.
6. Improvement of the regulatory framework for the management of human resources including an update of the Regulation for the JINR staff and other standard documents currently in force as well as development of new documents in view of the dynamics of JINR development.
7. Implementation of a complex of measures providing a special status of JINR executive officers in the host country of JINR in accordance with “Agreement between the Government of the Russian Federation and JINR on the Location and Terms of Activity of JINR in the Russian Federation”.

II. Efficiency of work, improvement of the management system

1. Regular assessments of work of staff members on the basis of relevant provisions of the JINR regulations for the assessment of personnel' work, rules for the assessment of individual efficiency of work of scientific researchers and other standard documents with the use of the PIN personal information system.

   Monitoring of the performance of JINR subdivisions taking into account the international experience and the system of assessment of the organizations of public sector of science operating in the territory of the host country of JINR.
2. Optimization of the structure and number of the personnel and adaptation of the JINR schedule of positions and salaries to the changing conditions.
3. Optimization of the management system of JINR providing efficiency of management processes and management expenses at increased requirements to the professional level and executive discipline of the personnel.
4. Improvement of competitive procedures in vacancy filling at JINR.
5. Organization of a system of electronic document flow providing efficiency and transparency of the administrative services offered to the JINR staff.
6. Implementation of the JINR policy concerning the protection and use of intellectual property created by employees of the Institute.

Personnel forecast by categories (FTEs quantity)

	2017	2018	2019	2020	2021	2022	2023
JINR personnel, including:	3 850	3 925	4 018	4 130	4 210	4 190	4 180
- researchers	1 223	1 223	1 226	1 235	1 215	1 230	1 230
- specialists, managers, employees, workers	2 627	2 702	2 792	2 895	2 995	2 960	2 950
Associate personnel	0	0	0	0	0	150	250
Total	**3 850**	**3 925**	**4 018**	**4 130**	**4 210**	**4 340**	**4 430**

Personnel forecast by countries (FTEs quantity, without associate personnel)

	2017	2018	2019	2020	2021	2022	2023
Russian Federation	3 441	3 506	3 562	3 667	3 752	3 725	3 712
Other Member States	380	390	417	425	417	420	420
Non-Member States	29	30	38	38	41	45	48
Total	**3 850**	**3 925**	**4 018**	**4 130**	**4 210**	**4 190**	**4 180**

III. Salary, social policy

1. Achievement, by the end of 2018, a level of average salary for the scientific researchers twice higher than the average salary in the host region of JINR.
2. Improvement of the remuneration system for all the categories of the JINR staff taking into account the international experience and the changes in legislation of the host country of JINR, aiming at transparency and efficiency of this system. Implementation of salary scales for all the categories of personnel with subdivision on sub-categories, aiming at growth of personnel motivation.
3. Reduction of disproportions in salaries of employees from different Member States, also by reducing levels of additional remunerations.
4. Modernization of workplaces of the JINR personnel at modern material and technical level.
5. Implementation of effective management of operation, granting and accounting of the JINR housing stock.
6. Effective use of the system of compulsory and voluntary medical insurance, rational interaction with healthcare institutions for granting high-quality medical services to the JINR personnel.
7. Improvement of the system of the accounting of work, including in hazardous and harmful and working conditions, and of the procedure for the preparation of documents confirming the right of staff members for labor pensions in the Member States of JINR.

   Use of the system of non-state pension provision in the host country of JINR depending on the level of its development and stability.
8. Extension of the material and social support of JINR veterans.

IV. Young Staff at JINR

A special programme entitled “Young Staff at JINR” was approved within the efforts to attract, train and recruit young scientists for the Institute. Financial and social support system for young people, their education and training, development of the environment for professional growth, promotion of their motivation towards scientific research or administrative work will be further developed in within this programme. The programme envisions preservation of the current successful projects implemented under the previous seven-year plan at the same time.

Implementation of the previous Seven-year plan has confirmed the effectiveness of realization and further development of grants for young staff and annual youth awards. The proportion of young people in the structure of the JINR staff is growing and the number of new young employees increases, which confirms the well-tuned recruitment system. On the other hand, the trend of outflow of staff with small work experience has remained — mainly because of unresolved housing conditions, which need special attention in the near future. Measures for the selection and increase of education and professional level of young staff are at the same level of importance for the further dynamic development of JINR as an international research organization.

The following are the main activities in the frame of the action plan for additional efforts to attract, train and recruit young scientists and specialists at JINR:

1. Establishment and development of the JINR basic facilities in accordance with international status and advanced research worldwide.
2. Further development of a world-class competitive educational platform based on the engineering center and UC programs.
3. Promotion of the Institute and its activities through conferences, schools, seminars and public lectures, scientific excursions and presentations for the specialists and the public.
4. Further implementation and development of the young staff grants system and annual youth awards.
5. Implementation of the career road map, which indicates opportunities for young staff, creation of the youth talent pool at JINR divisions.
6. Further development of the financial and social support system for young staff aimed to improve the quality of life and work conditions.
7. Increasing and improving the quality of special housing fund, ordering rent payment of young staff.
8. The housing programme on favorable terms — loans and subsidies for the accommodations, opportunity of beneficial purchase of special housing fund with payment by installments.

The time scale for the implementation of the planned actions for this section of the Seven- year plan, and determination of specific objectives and stages in 2017–2023 will depend on the general conditions of the JINR development and changing external factors influencing the personnel and social policy.

Financial Support

1. Income

Revenues of the JINR financial plan for 2017–2023 (M$)

	2017	2018	2019	2020	2021	2022	2023	Total
Contributions of the Member States of JINR	197.3	196.9	201.0	200.2	209.2	217.0	222.4	**1 444.0**
Payment of arrears of the JINR Member States for the payment of contributions	47.6	0.1	30.6	12.8	0.2	0.2	0.2	**91.7**
Other income	9.2	8.8	8.4	5.9	2.2	0.0	0.0	**34.5**
Total	**254.1**	**205.8**	**240.0**	**218.9**	**211.6**	**217.2**	**222.6**	**1 570.2**

The revenues of the JINR Financial Plan are formed mainly from the contributions of the Member States. The increase in the estimated amount of contributions for 2022 and 2023 is 2.5% annually. The income also includes the payment of arrears of Member States in the payment of contributions, in accordance with the approved schedules, and the collection of other income.

Taking into account actually received funds, the total amount of revenues for 2017–2023 is planned in the amount of 1,570.2 M$.

2. Expenditures

Expenditures of the JINR financial plan for 2017–2023 (M$)

	2017	2018	2019	2020	2021	2022	2023	Total
Personnel	65.3	73.1	82.1	79.4	96.7	112.9	114.8	**624.3**
International cooperation	8.4	8.7	8.9	3.1	5.6	6.0	6.0	**46.7**
Material costs, external R&D, construction	96.8	103.7	100.4	91.8	108.4	106.8	76.0	**683.9**
Energy and water	4.8	4.9	4.9	4.2	5.3	5.5	5.8	**35.4**
Overhaul	9.6	10.9	13.3	15.6	11.1	10.0	10.0	**80.5**
Operating expenses	9.5	10.3	10.7	10.0	10.2	10.0	10.0	**70.7**
Total	**194.4**	**211.6**	**220.3**	**204.1**	**237.3**	**251.2**	**222.6**	**1 541.5**
Reserve for plenipotentiary grants and cooperation programs	–	–	–	–	10.0	7.0	7.0	**24.0**
Reserve for grants from the JINR Directorate	–	–	–	–	10.5	10.7	11.0	**32.2**
Total	**194.4**	**211.6**	**220.3**	**204.1**	**257.8**	**268.9**	**240.6**	**1 597.7**

Expenditures of the JINR financial plan are presented in the form of consolidated items reflecting the main directions of spending the funds. The main part of expenses is concentrated in two consolidated items: “Personnel” and “Material costs, external R&D, construction”.

The consolidated item “Personnel” includes expenses related to wages and salaries. The level of remuneration of employees and the attractiveness of the Institute for highly qualified scientists and young specialists depend on these costs.

The consolidated item “Material costs, external R&D, construction” includes expenses for the purchase of materials, equipment, commissioning fees, payments for research and development work performed by third-party organizations, as well as expenses for the design and construction of buildings, structures and technological systems. These costs are mainly related to the implementation of scientific projects.

Also, the expenses include other consolidated items that ensure the efficient operation of JINR: “International cooperation” — expenses for business trips, reception of specialists and holding meetings and conferences; "Energy and Water" — the cost of paying for electricity, heat, water supply and wastewater; "Repair" — expenses for major and current repairs of buildings, structures and equipment; "Operational expenses" — the costs of scientific, information and engineering and technical support, payment for transport services, communications, security of facilities, social services and other service costs.

Expenditures also include reserve funds that are earmarked and are allocated to expense items throughout the year.

The total amount of expenditures for 2017–2023 is planned in the amount of 1,597.7 M$.

3. Material costs (consolidated item "Material costs, external R&D, construction")

Expenditure for the consolidated item “Material costs, R&D, construction (M$)

	2017	2018	2019	2020	2021	2022	2023	Total
Accelerator complex NICA	38.3	46.5	38.9	32.2	49.3	53.3	26.7	**285.2**
Cyclotron complex DRIBs-III	17.1	12.4	10.5	11.4	14.1	15.0	13.1	**93.6**
Neutrino program	12.2	9.8	13.0	9.1	7.9	5.0	3.2	**60.2**
IBR-2 and spectrometers	4.5	7.2	6.9	4.8	4.6	3.5	2.4	**33.9**
Multifunctional information and computing complex	3.1	4.7	3.0	4.0	2.9	3.1	3.3	**24.1**
Other scientific projects, including the Innovation Center, SOLCRYS Laboratory, “Govorun” supercomputer	9.2	9.5	12.1	10.9	8.2	10.1	10.3	**70.3**
Total for all research projects	**84.4**	**90.1**	**84.4**	**72.4**	**87.0**	**90.0**	**59.0**	**567.3**
Operation of basic installations	3.6	4.3	5.4	3.1	4.2	4.3	4.7	**29.6**
Laboratories infrastructure	2.1	1.6	3.0	3.3	4.2	3.5	3.3	**21.0**
JINR infrastructure	6.7	7.7	7.6	13.0	13.0	9.0	9.0	**66.0**
Total	**96.8**	**103.7**	**100.4**	**91.8**	**108.4**	**106.8**	**76.0**	**683.9**

A significant part of the material expenditures is aimed at financing the main scientific projects of JINR:

– establishment of the NICA accelerator complex for research in the field of high-energy heavy ion physics;

– establishment of the DRIBs-III cyclotron complex to search for new superheavy elements of the periodic table and study the properties of radioactive and exotic neutron-rich nuclei;

– development of the IBR-2 nuclear research facility and spectrometers for research in the field of condensed matter physics and in the field of nanotechnology;

– implementation of the Neutrino research program in the field of neutrino physics, astrophysics and dark matter;

– development of a multifunctional information and computing complex to support scientific activities.

These costs are based on detailed cost estimates and project implementation schedules approved by the JINR Scientific Council and Program Advisory Committees.

In material expenditures, funds are also planned for the operation and maintenance of existing experimental installations in order to maintain them in proper working order, costs for administrative and economic services, as well as costs for the maintenance and development of institution-wide engineering systems.

4. Personnel costs (consolidated item “Personnel”)

Personnel costs are planned in a volume that ensures competitive level of remuneration and attractiveness of the Institute for highly qualified scientists and young specialists.

Starting from 2021, a centralized fund for stimulating highly qualified personnel is planned annually in personnel costs, which was created by the decision of the JINR CP in order to ensure a competitive level of remuneration, stimulate employees to improve their qualifications and professional competence, and solve the problems of concentrating resources in priority areas of JINR's activities.

Directorate of the Institute approved the directions for using the funds of the fund:

– support for the development of the main projects of the Institute – NICA, the SHE factory, IBR-2, the neutrino program, etc., within the framework of which we are talking about supporting representatives of all categories of personnel involved in projects, but the main task of using this part of the fund is to stimulate engineering and technical laboratory personnel;

– support for young researchers without a scientific degree through the mechanism of salary increments, and in the future – through an increase in the number and size of JINR grants for young scientists and specialists;

– special programs for the development and attraction of high-level personnel, which include a competitive program of postdocs, the recruitment of promising graduate students for the positions of research trainees, one-time payments for successful defense of dissertations, the attraction of outstanding researchers to full-time work at the Institute;

– support of highly qualified researchers in the person of candidates and doctors of science;

– rewarding teams for special achievements in the implementation of large-scale projects of the Institute.

Average personnel salary at JINR (thousands of Russian rubles)

	2017	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
Average monthly salary of JINR scientists, taking into account all payments is not less than	95.9	108.6	125.2	139.5	159.2	164.2	169.3
Average monthly salary at JINR, taking into account all payments is not less than	70.2	78.6	88.6	96.4	110.6	114.0	117.6

5. ISTC, “Energy and water”, “Repairs”, “Operating costs”

Expenditures under the consolidated item “International cooperation” are financially planned for 2021–2023 in accordance with the current level. Additional financing of these costs will be carried out at the expense of funds reserved for grants from plenipotentiaries, programs of cooperation with scientific organizations of the Member States, as well as joint projects with scientific organizations of non-JINR member states, with which agreements on scientific and technical cooperation have been concluded.

Expenditures under the consolidated item "Energy and Water" are planned based on the estimated consumption of energy resources by the experimental installations and facilities of the Institute. The calculation also takes into account the forecasted growth in tariffs for the services of companies in the fuel and energy complex in the Russian Federation.

The amount of funds for the consolidated item of expenditure "Repair" was determined taking into account the need to update and expand production areas that ensure the operation of new experimental installations, the development of engineering infrastructure, an increase in the number of modern research jobs in the laboratories of the Institute, as well as the costs of the current maintenance of buildings and structures of the Institute. Repairs in 2021–2023 are projected to be at roughly the same level of about $ 10.0 million USD annually.

Expenditures under the consolidated item “Operating expenses” are planned for 2021–2023 at the level of 10.0 million USD annually, taking into account their optimization in order to concentrate funds to ensure the implementation of scientific projects.

6. Financial risks and a reserve for grants from the JINR Directorate as a measure to minimize their negative consequences

The main risks of the financial plan for the development of JINR are associated with the emergence of a deficit in the event of non-payment of contributions by individual Member States, as well as in the event of an unfavorable situation with exchange rates.

The emergence of a deficit in the JINR budget will lead to the need to limit budget expenditures, which may negatively affect the timing of the implementation of major scientific projects.

The financial plan provides for a reserve for grants from the JINR Directorate in the amount of 5% of the total amount of contributions, which is under the operational management of the Director of the Institute. These funds are necessary to mitigate the negative impact on the Institute's budget in the event of adverse circumstances. They can also be aimed at providing additional needs arising in the process of budget execution.

7. Forecast macroeconomic indicators

While forming expenditures of the JINR Financial Plan for 2021–2023, the forecasted macroeconomic indicators expected in the country where the JINR is located were used. The figures are based on the official forecasts of the Ministry of Economic Development of the Russian Federation.

Forecast macroeconomic indicators

	2017	2018	2019	2020	2021	2022	2023
Average annual US dollar exchange rate, rubles for 1 US dollar	58.3	62.5	64.7	71.9	70.8	73.1	73.8
Average annual euro exchange rate, US dollars for 1 euro	1.13	1.18	1.12	1.14	1.15	1.20	1.20
Average annual inflation (price increase) in the host state of the Institute	3.7%	2.9%	4.5%	3.4%	4.0%	4.0%	4.0%
Average annual increase in electricity tariffs	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%
Average annual growth of tariffs for heat energy and water supply	4.0%	4.0%	2.4%	4.0%	4.0%	4.0%	4.0%

8. Financing of the NICA project at the expense of earmarked funds of the Russian Federation

The implementation of the NICA project is carried out by joint efforts of JINR and the Russian Federation in accordance with the Agreement on the creation and operation of a complex of superconducting rings on colliding beams of heavy ions NICA of April 26, 2016.

In accordance with this Agreement, as well as its updating in accordance with the National Project "Science", funding is carried out at the expense of the JINR budget, contributions from other countries and at the expense of funds allocated under the Agreement by the Russian Federation.

The total amount of funds allocated by the Russian Federation for the creation of the NICA accelerator complex is 14,400.0 million rubles.

The use of funds from the Russian Federation is carried out in accordance with the Agreement and decisions of the Supervisory Board of the NICA project. The table below shows the structure of the actual use of these funds for 2017–2020, as well as the plan for their use for 2021–2023[1].

[1] 267.6 million rubles were spent on the implementation of the NICA project in 2016.

NICA project expenditures secured by earmarked contribution of the Russian Federation (millions of Russian rubles)

	2017	2018	2019	2020	2021	2022	2023	Total
Establishment of experimental installations	552.7	552.7	902.7	347.9	1 110.8	1 536.7	0.0	5 003.5
Research and engineering infrastructure	753.4	761.1	1 171.3	1 272.9	1 995.0	711.8	500.0	7 165.5
Computer information complex	34.8	400.6	113.9	0.0	91.5	11.8	300.0	952.6
Channels and installations for applied innovation research	0.0	0.0	46.8	62.9	590.1	311.0	0.0	1 010.8
Total	**1 340.9**	**1 714.4**	**2 234.7**	**1 683.7**	**3 787.4**	**2 571.3**	**800.0**	**14 132.4**

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