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**