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 $\sqrt{s\text{NN}}$=4–11 GeV, also with beams of polarized protons ($\sqrt{s\text{NN}}$ up to 26 GeV) and deuterons ($\sqrt{s\text{NN}}$ 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 — 2017; first configuration of the collider — 2020; design configuration of the collider — 2023). Development of experimental zones and extracted beam channels of the NICA complex (channels for transportation of heavy and light ions, polarized particles, the test channel and associated infrastructure — 2017–2019).
2. Creation and start-up of an infrastructure for carrying out 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 — 2019.
5. Start-up of the MPD Stage I— 2019.
6. Commissioning of the MPD Stage II — 2023.
7. Start-up of SPD — 2023.

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

	2017	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**Total**
Injection complex	405.7	358.3	331.4	309.3	717.9	686.2	149.4	**2 958.2**
Booster	5 907.4	2 319.8	890.2	112.5	0.0	0.0	0.0	**9 229.9**
Nuclotron	434.7	330.1	615.5	553.0	258.4	0.0	0.0	**2191.7**
Collider	8 196.2	8 195.1	16 136.6	16 943.2	10 723.8	5 318.8	2 682.5	**68 196.2**
Cryogenic complex	4 118.8	4 775.8	2 091.3	1 398.5	687.2	714.0	713.4	**14 499.0**
BM@N	1 380.8	1222.0	1139.5	1041.0	885.9	736.4	643.7	**7049.3**
MPD	10 203.3	10 034.1	6 281.2	6 870.3	5 781.3	4 447.7	3 259.4	**46 877.3**
SPD	92.1	87.3	87.7	468.6	497.7	5 664.4	7 556.8	**14 454.6**
Magnet workshop	242.1	232.0	233.0	230.6	235.5	49.7	39.7	**1 262.6**
Computing	154.4	159.1	383.3	372.3	244.5	254.0	253.7	**1 821.3**
NICA infrastructure	25 831.6	20 294.1	7 538.0	93.7	76.6	49.7	49.7	**53 933.4**
Other expenses	2 000.0	2 050.0	2 100.0	2 250.0	2 300.0	2 350.0	2 400.0	**15 450.0**
Total	**58 967.1**	**50 057.7**	**37 827.7**	**30 643.0**	**22 408.8**	**20 270.9**	**17 748.3**	**237 923.5**

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 pμA) for nuclei with $A \leq 100$; 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 ($T_{1/2} \geq 0.1$ 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								
Development of new physical set-ups (gas catcher, pre-separator for chemical investigations, and detecting modules)	5 400.0	3 600.0	4 400.0	2 800.0	1 700.0	2 500.0	3 500.0	**23 900.0**
Experimental hall of U400R								
Reconstruction of supporting systems of Building 131	300.0	1 400.0	1 100.0	0.0	0.0	0.0	0.0	**2 800.0**

Reconstruction of the experimental hall	0.0	500.0	300.0	4 700.0	6 700.0	3 000.0	0.0	**15 200.0**
Subtotal	300.0	1 900.0	1 400.0	4 700.0	6 700.0	3 000.0	0.0	**18 000.0**
Modernization of the U400R cyclotron								
Completing systems	0.0	0.0	0.0	1 400.0	1 400.0	0.0	0.0	**2 800.0**
Beam lines	0.0	0.0	0.0	500.0	1 000.0	2 000.0	2 000.0	**5 500.0**
Subtotal	0.0	0.0	0.0	1 900.0	2 400.0	2 000.0	2 000.0	**8 300.0**
Modernization of the U400M cyclotron								
New main magnet electromagnetic coils	1 000.0	900.0	0.0	0.0	0.0	0.0	0.0	1 900.0
Vacuum and beam diagnostic systems	800.0	1 400.0	500.0	0.0	0.0	0.0	0.0	2 700.0
Automated radiation monitoring system	200.0	300.0	300.0	0.0	0.0	0.0	0.0	800.0
Subtotal	2 000.0	2 600.0	800.0	0.0	0.0	0.0	0.0	**5 400.0**
Construction of new and development of running set-ups (U400R and U400M cyclotrons)								
Electromagnetic separators, multiparametric α-, ß-, γ-detection system	2 400.0	1 400.0	3 800.0	900.0	1 000.0	4 200.0	6 000.0	**19 700.0**
Support for experiments								
Provision for experiments, including targets, enriched isotopes, detection systems, and liquid nitrogen	3 900.0	4 300.0	3 800.0	3 800.0	2 900.0	4 000.0	4 500.0	**27 200.0**
Total	**14 000.0**	**13 800.0**	**14 200.0**	**14 100.0**	**14 700.0**	**15 700.0**	**16 000.0**	**102 500.0**

Beam time (on target) (h)

	2017	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**Total**
U400/U400R	5 000	5 000	5 000	2 500	0	0	2 500	**20 000**
U400M	5 000	5 000	0	2 500	5 000	5 000	5 000	**27 500**
DC-280	0	5 000	5 000	5 000	5 000	5 000	5 000	**30 000**
Total	**10 000**	**15 000**	**10 000**	**10 000**	**10 000**	**10 000**	**12 500**	**77 500**

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.).

3. Feasibility study for the design of a new neutron source (NNS). Realization of pre-project work for the NNS.

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 neutron-beam-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**
Implementation of the final configuration and development of new spectrometers DN-6, GRAINS, spectrometer of tomography and radiography, FSS	602.3	580.4	557.5	500.6	469.4	465.3	447.2	**3 622.7**
Upgrade of the existing IBR-2 spectrometers	481.0	483.6	532.9	616.2	638.5	839.1	968.8	**4 560.1**
Development and construction of the basic configuration of a new small-angle scattering spectrometer	314.6	251.5	236.9	269.6	338.0	267.0	223.6	**1 901.2**
Optical methods of research	55.0	56.0	57.0	59.0	60.0	62.0	63.0	**412.0**

Development of the IBR-2 reactor with a complex of cryogenic moderators	1 793.7	1 786.2	1 967.6	1 754.6	1 509.7	1 558.5	1 603.0	**11 973.3**
Development of monitoring and control systems of cold neutron moderators and actuators of spectrometers	305.7	249.9	254.1	211.8	206.6	183.1	178.9	**1 590.1**
Development of detectors, sample environment systems, data acquisition and accumulation systems, FLNP's information and computing infrastructure	952.0	854.4	951.0	1 005.2	1 062.8	1 190.0	1 259.5	**7 274.9**
IBR-2 operation costs	348.0	893.0	759.0	827.0	849.0	916.0	952.0	**5 544.0**
Total	**4 852.3**	**5 155.0**	**5 316.0**	**5 244.0**	**5 134.0**	**5 481.0**	**5 696.0**	**36 878.3**

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.

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

	2017	2018	2019	2020	2021	2022	2023	Total
Maintenance and operation	400.0	428.0	458.0	490.0	524.0	1 160.0	1 200.0	**4 660.0**
Upgrade of accelerator systems	673.0	700.0	700.0	500.0	300.0	200.0	100.0	**3 173.0**
Modernization of the experimental hall	781.0	912.0	1 025.0	1 346.0	1 676.0	1 515.0	1 563.0	**8 818.0**
Total	**1 854.0**	**2 040.0**	**2 183.0**	**2 336.0**	**2 500.0**	**2 875.0**	**2 863.0**	**16 651.0**

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.

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**
PMTs Hamamatsu R7081-100	2 100.0	2 100.0	2 100.0	2 100.0	2 100.0	2 100.0	2 100.0	**14 700.0**
Glass pressure holdings with connectors	1 000.0	1 000.0	1 000.0	1 000.0	1 000.0	1 000.0	1 000.0	**7 000.0**
Electronics and computing	1 100.0	1 250.0	1 400.0	1 400.0	1 400.0	1 400.0	1 400.0	**9 350.0**
Underwater connection cables	500.0	500.0	700.0	700.0	700.0	700.0	700.0	**4 500.0**
Infrastructure and transport (shore computer center, labs, living buildings. vehicles for winter work)	800.0	800.0	800.0	800.0	800.0	800.0	800.0	**5 600.0**
Total	**5 500.0**	**5 650.0**	**6 000.0**	**6 000.0**	**6 000.0**	**6 000.0**	**6 000.0**	**41 150.0**

Planned schedule for GVD production and development

	2017	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**Total**
Clusters to install per year	1	2	2	2	2	3	3	**15**
Clusters in the detector	2	4	6	8	10	13	16	**59**
Production of optical modules per year	600	600	600	600	900	900	900	**5100**