JOINT INSTITUTE FOR NUCLEAR RESEARCH

SEVEN-YEAR PLAN

FOR THE DEVELOPMENT OF JINR

2010–2016

(Approved by the Committee of Plenipotentiaries of the Governments of the JINR Member States at its session held on 19–21 November 2009)

Dubna 2009

Contents

General editorship: A. Sissakian, M. Itkis, R. Lednický.

Authors: V. Bednyakov, A. Belushkin, S. Dmitriev, D. Fursaev, V. Ivanov, V. Katrasev,
V. Kekelidze, E. Krasavin, S. Nedelko, A. Olshevskiy, D. Peshekhonov, A. Popeko,
N. Russakovich, A. Ruzaev, G. Shirkov, T. Strizh, V. Shvetsov, E. Strokovsky, V. Voronov.

Photo: P. Kolesov, E. Puzynina, Yu. Tumanov.

Editor of the English text: O. Kronshtadtov.

Introduction

The Seven-Year Plan for the Development of the Joint Institute for Nuclear Research for the years 2010–2016 has been elaborated on the initiative of the JINR Directorate, supported by the Scientific Council of the Institute and the Committee of Plenipotentiaries of the Governments of the JINR Member States, in line with the strategic provisions of the JINR Road Map (JINR Road Map Updated, JINR Edition 11-8396, 2008).

The concept of the Seven-Year Plan is based on the concentration of resources to update the accelerator and reactor base of the Institute. The key elements of the qualitative improvement of the research infrastructure are the following basic facilities:

– the ion collider NICA (Nuclotron-based Ion Collider fAcility) for research in the field of high-energy heavy-ion physics. Implementation of this project will result in construction of a unique accelerator complex— a cascade of accelerators that will allow a rich programme of fundamental physics studies to be carried out in a region, inaccessible to date, of energies and masses of interacting particles;

– the cyclotron complex DRIBs-III (Dubna Radioactive Ion Beams) for the search for new superheavy elements of Mendeleev's Periodic Table and for studies of the properties of radioactive and exotic neutron-rich nuclei;

– the modernized reactor IBR-2M for research in condensed matter physics and particularly in the fields of nanoscience and nanotechnology.

The Joint Institute for Nuclear Research is an international scientific organization which is open for cooperation with all countries of the world. One of the purposes of this publication is to spread information about the unique basic facilities of the Institute and their subsequent integration into the common European research infrastructure (the European Roadmap for Research Infrastructures).

Particle Physics and High-Energy Heavy-Ion Physics

Referring to the JINR Road Map, the scientific research in the field of modern 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 themes:

1. Particle physics research, including 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 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, which includes the **Nuclotron-M** accelerator and the **NICA** collider, and within the framework of international partnership programmes at the world’s largest accelerator facilities like the Tevatron (FNAL), RHIC (BNL), LHC and SPS (CERN), FAIR (GSI) in the experiments with essential contribution made by the Institute’s staff.

JINR also participates in both accelerator and detector activities within the **ILC** project. In particular, Dubna is officially considered to be one of the possible places for ILC siting. The natural continuation of this effort is the involvement in the R&D for detectors and preparation of the ILC physics programme. VBLHEP and DLNP plan to continue the R&D work on construction of free-electron laser elements, construction of ILC photoinjector prototype (in collaboration with DESY and KEK), commissioning of the LINAC-800 based test-bench with electron beams, RF and diagnostic systems, built-in equipment, metrological laser complex, design of the fourth generation cryogenic modules, technology of bimetallic explosion welding of cold mass elements (collaboration with VNIIEF (Sarov)). The JINR groups have also joined in developmental work for the international projects **FLASH** and **XFEL**. It is planned to participate in the development of diagnostic systems of ultra-short bunches in the linear accelerator, experimental study of coherent radiation, construction of units for X-ray laser irradiation diagnostics, development of diagnostics for large cryogenic systems.

In 2010–2016, the **Veksler and Baldin Laboratory of High Energy Physics** (VBLHEP) will preserve its main directions of research in high-energy heavy-ion physics and modern particle physics which, in particular, include investigations of the nucleon spin structure, tests of the Standard Model, search for new physics, and the study of CP violation. During the same period the **Dzhelepov Laboratory of Nuclear Problems** (DLNP) will also continue its investigations in elementary particle physics, in particular, in the traditional for JINR field of neutrino physics and rare processes. DLNP will take part in the development of JINR’s new domestic basic facilities as well.

The **research in high-energy heavy-ion physics at JINR** will be carried out at the VBLHEP accelerator complex (Nuclotron-M and NICA) the construction of which is the primary objective of this Laboratory. At this complex, within the **MPD** project, an experimental study of the properties of hot and dense hadronic matter, and search for the so-called “mixed phase” of such matter, i.e. a mixture of quark-gluon and hadron states, as well as for a possible phase transition will be performed at the energy of colliding particles up to $\sqrt{s_{NN}}$ =11 GeV.

The degree of involvement of VBLHEP groups in research on **high-energy heavy-ion physics at the world's accelerator laboratories** will be defined by the progress of activities on the NICA/MPD project and the emerging opportunities for work at the **Nuclotron-M/NICA** accelerator complex. At the same time, VBLHEP scientists will participate in the study of the properties of nuclear matter in states with extremely high density and temperature, in the search for manifestations of quark deconfinement and possible phase transitions within joint research on heavy-ion physics in the experiments **STAR** at the RHIC collider (BNL), **NA61** (SPS) and **ALICE** (LHC) by investigating the production of various hadrons including light vector mesons and heavy quarkonia, as well as in measurements of direct photon and dilepton yields.

Under the **FASA** project at the **Nuclotron-M** until 2011–2012, experiments are planned to study the processes of multiple emission of medium-mass fragments using relativistic beams of light ions. It is expected to determine the mechanism of multifragmentation and obtain information about nuclear phase transitions of the liquid-fog and liquid-gas types.

The study of processes occurring in collisions of heavy nuclei at the energies up to 2 GeV/n by way of lepton pair detection is being performed by VBLHEP scientists with the help of the **HADES** wide-aperture spectrometer at the **SIS-18** accelerator (GSI). After the start-up of the **SIS-100** accelerator, work at HADES will be continued at the energies of this accelerator (~10 GeV/n).

The **CBM** set-up is being constructed to study high-energy heavy-ion interactions at the new international accelerator centre **FAIR** (Facility for Antiproton and Ion Research) in Darmstadt, Germany. The CBM experimental complex is intended for investigations associated with the programme on the search for and study of the mixed phase in the "fixed target" experiment scenario. Experiments with CBM are complementary to those with the MPD facility at the NICA collider. The JINR team is involved in designing and building a part of the track detectors for CBM and actively participates in the simulation of elements of this set-up and in the elaboration of the physics programme.

The goal of the **THERMALIZATION** project conducted at the modernized SVD facility is to study the collective behavior of secondary particles produced in pp interactions at the proton beam energy of 70 GeV (Protvino). The programme of investigations includes measurements of partial cross sections of pp interactions at a high number of secondary charged particles, study of multiparticle correlations, search for turbulence signals for the excited hadron matter, etc. The project is planned to be completed in 2011.

The study of the nucleon spin structure will be carried out by JINR scientists at the VBLHEP accelerator complex and at CERN and BNL. A series of experiments are planned to be conducted with the extracted polarized beams of the Nuclotron-M, particularly, using a movable polarized target. These investigations are associated with preparations for implementing the spin programme of the NICA project and are aimed at creating effective polarimetry as well as at developing technology for polarized targets and polarized particle sources. Under this programme, during the period up to 2011–2012, it is expected to carry out investigations on the measurement of polarized observables using the **DSS** and **ALPOM-2** facilities.

The **DSS** experiment conducted in collaboration with RIKEN is aimed at measuring spin-dependent observables in the ^{3}He(d,p)^{4}He reaction at the energies T_d=1.0–1.75 GeV, which corresponds to the core area in the deuteron, using the polarized deuteron beam at the Nuclotron and polarized ^{3}He-target fabricated at the CNS (Japan). The goal of the **ALPOM-2** project is to measure the analyzing power in the p+CH_2 reaction at momenta of polarized proton beams from 3 to 6 GeV/c. These data are necessary for the planned experiments on the measurement of the ratio of nucleon electric and magnetic form factors at a large four-momentum transfer.

The investigation of the hadron structure and hadron spectroscopy using high-intensity muon and hadron beams is the purpose of the **COMPASS** experiment (CERN, SPS). The JINR team will take part in measurements of generalized parton distributions, in the study of the

Matveev-Muradyan-Tavkhelidze-Drell-Yang (MMTDY) processes as well as in the study of the longitudinal and transverse structure of the nucleon. In 2010–2016, JINR will participate in data taking, processing, and analysis. The scientific programme of the COMPASS experiment will be continued at the **NICA** accelerator complex under the **SPD** project whose start-up is expected to take place in 2016–2017.

The spin programme of the **STAR** project is targeted at measurements of spin-dependent structure functions of nucleons and nuclei using polarized beams of the **RHIC** accelerator (BNL). The JINR team plans to continue participating in this programme of the STAR experiment until the SPD facility has been put into operation at NICA.

Test experiments to validate the anti-proton polarization method are in progress at COSY (Jülich) and AD (CERN) with DLNP's participation. If successful, the PAX project at FAIR to perform spin physics measurements will be elaborated.

In the next seven years, JINR's most important activity in particle physics will concern **verification of the Standard Model, search for new phenomena beyond its realm and study of fundamental symmetry violations**. These investigations are already carried out and will be continued by DLNP and VBLHEP groups within large international collaborations at the world-best accelerator complexes, in experiments with significant or dominant contribution made by JINR scientists. These are nowadays the experiments at the proton-antiproton **Tevatron** collider (FNAL), where DLNP physicists participating in the research work with the CDF and D0 detectors have already obtained physics results of fundamental importance. Data analysis will continue till 2012. The experience gained by these scientists at the Tevatron will be extremely important for JINR's effective participation in future experiments at the LHC.

It is obvious that a new era of fundamental investigations in particle physics will be opened when the **LHC** collider starts operation at CERN. DLNP, BLTP, LIT and VBLHEP scientists will take part in the ATLAS and CMS experiments at the LHC. These two experiments are designed to make excellent measurements of many possible (known and unknown) products of collisions at the unprecedented centre-of-mass energy of 14 TeV. The goal of the **ATLAS** project is to study proton-proton interactions using to the maximum extent the resources and capabilities of the LHC collider to investigate various physics processes with a view to verifying predictions of the Standard Model and search for phenomena beyond its scope. JINR's team is involved in the activities on a number of major physics tasks (top quark, Higgs boson and supersymmetry searches, etc.) and is responsible for maintaining the key subsystems of the experimental facility. JINR is taking part in the **CMS** project within a joint collaboration of Russia and JINR Member States (RDMS CMS). The RDMS collaboration is fully responsible for the endcap hadron calorimeters and forward muon stations. In 2010–2016, the JINR group will participate in data taking, monitoring of the detection systems, maintenance of their operation, data processing with the aim of testing the Standard Model in the MMTDY processes, and in the search for signals from new physics. QCD investigations, study of jet events, measurements of their cross sections for the purpose of verifying gluon structure functions, and a study of production of massive states (gauge bosons, Higgs bosons) will also be performed.

In the **DIRAC** experiment at the PS accelerator at CERN, DLNP scientists continue studies of low-energy QCD parameters followed from chiral symmetry violation. Plans to improve measurements using SPS beam and completion of these studies in 2014 will be considered.

Measurements of CP violation are currently very important for the understanding of the nature of CP violation within the Standard Model. Under the **NA62** project at the CERN **SPS** beam, VBLHEP continues a series of high-precision experiments aimed at investigating the phenomenon of direct CP violation in the kaon decay and a wide range of other properties of these decays with unprecedented accuracy. The NA62 set-up is being developed to enable the study of the ultra-rare decay of a charged kaon into a charged pion and two neutrinos. The measurement of its probability will allow one to significantly improve the parameters of the Cabibbo-Kobayashi-Maskawa matrix and, probably, find manifestations of new physics. The tasks of the JINR team for 2010–2016 include building (jointly with CERN) a track detector of new type, developing software for simulation and reconstruction of tracks in the detector and for the entire NA62 experiment, and participating in experimental data taking, processing, and analysis.

The results, obtained with DLNP's participation in the E391a experiment at KEK on the decay of a neutral kaon into a pion and a neutrino-antineutrino pair, allow one to consider continuation of this research at a higher precision level which may lead to a new understanding of the CP-violation effect. Future DLNP plans are related with the experiment **KLOD** at IHEP (Protvino) and with the NA62 experiment at CERN.

Precision studies of rare muon and pion decays allow one to test the Standard Model of electroweak interaction and μ-e universality. It is proposed by DLNP to conduct a search for the μ^+ decay into $e^+\gamma$ which violates the lepton number conservation law (MEG project). Modern extensions of the Standard Model predict measurable lepton-flavour-violating μ^+ decay into $e^+\gamma$. The proposed experiment with the sensitivity of 10^{-14} (relative to the main decay scheme) at the PSI accelerator provides a good chance to obtain first evidence for existence of new physics beyond the Standard Model.

The search for manifestations of polarized hidden strangeness of nucleons in the production of φ and ω mesons in proton-proton and neutron-proton interactions is the main goal of the **HyperNIS** project at the **Nuclotron-M**. The characteristics of the Nuclotron-M beams provide unique possibilities for the search of hypernuclei and study of their properties. The key task for the near future is to search for neutron-rich ${}^{6}_{\Lambda}H$ hypernuclei using the ^7Li beam. This programme of studies is planned to be completed in 2015.

JINR substantially participates in the **FAIR** accelerator and detector activities. The physics programme of the future FAIR facility covers a wide range of topics that address central issues of strong interactions and QCD. The antiproton beam in the momentum range from 1 to 15 GeV/s will allow the **PANDA** experiment to make high-precision measurements which include charmonium and open charm spectroscopy, the search for exotic hadrons and the study of in-medium modifications of hadron masses. During the next seven years JINR plans to participate in the PANDA experiment, contributing to the construction of the muon system, superconducting solenoid, and quartz radiators. It is expected that the main contribution of JINR to FAIR will be financed under the Russia–FAIR agreement.

Neutrino and rare phenomena physics offers promising possibilities to study fundamental, key issues of modern elementary particle physics. The **study of double-beta decay** processes has highest priority at DLNP, and will be carried out within the framework of the NEMO, GERDA-MAJORANA (G&M) and Super-NEMO projects. It is planned by 2016 to achieve with ^{82}Se the limit on an effective neutrino mass, $m_\nu < 0.04$–0.11 eV. The main purpose of the GERDA experiment is to search for the neutrinoless double-beta decay of ^{76}Ge. GERDA will operate with bare germanium semiconductor detectors (enriched in ^{76}Ge) situated in liquid argon. The experiment will be performed in the Gran Sasso Underground Laboratory (Italy).

Observation of **neutrino oscillations** requires neutrinos to have mass and lepton-flavor non-conservation. DLNP is taking part in leading experiments on neutrino oscillations such as the OPERA experiment (Gran Sasso), whose aim is to detect tau neutrino appearance with muon-neutrino beam from CERN's accelerator, and the Daya Bay reactor neutrino experiment.

At the GEMMA spectrometer situated at the Kalinin Nuclear Power Plant, experiments on measurement of the **neutrino magnetic moment** are performed. With the unique parameters of this instrument, the sensitivity is expected to be at the level of $3.5\cdot10^{-11}$ μ_B after data taking up to 2009. At the end of 2010, the new detector GEMMA-2 will start to operate with an increased neutrino flux from the reactor. It is planned to achieve with GEMMA-2 the sensitivity on the neutrino magnetic moment at the level of $(9–7)\cdot10^{-12}$ μ_B after operation during 2010–2012.

DLNP participates in the study of **ultra-high-energy cosmic rays** (within the projects TUS, NUCLEON and Baikal), in direct and indirect **dark matter search** (within the projects

EDELWEISS and Baikal). A direct observation of the interaction of Weakly Interacting Massive Particles (WIMP) in a terrestrial detector would be of tremendous importance to particle physics and cosmology. The EDELWEISS collaboration is searching for WIMP dark matter using cryogenic detectors. The development of EDELWEISS will be continued in the project called EURECA (European Underground Rare Event Calorimeter Array). The aim is to search for dark matter with the highest accuracy with a target mass of up to one ton. It is planned to begin the EURECA experiment in 2015.

To realize the ambitious JINR programme in particle physics and especially in high-energy heavy-ion physics, a specialized **VBLHEP Accelerator Complex** together with state-of-the-art detection systems will be built. To this end the **NICA** project has been prepared. Its aim is to create the accelerator base and infrastructure required for realization of the key physics task to be addressed by the Laboratory — experimental studies of hadronic (strongly interacting) matter and its phase transitions.

The chief goal of the project is to construct, based on the Nuclotron-M accelerator, a collider that will allow carrying out investigations with colliding beams of high-intensity ions at an average luminosity of $L=10^{27}cm^{-2}s^{-1}$ for Au^{+79} within the energy region $\sqrt{s_{NN}}$ = 4–11 GeV, as well as with polarized proton ($\sqrt{s_{NN}}$ up to 20 GeV) and deuteron ($\sqrt{s_{NN}}$ up to 12 GeV) beams with longitudinal and transverse polarization and with extracted ion beams as well as polarized proton and deuteron beams.

This requires creating a source of highly charged heavy ions, constructing a linear injector accelerator, designing and building a booster synchrotron, developing and constructing two superconducting storage rings, integrating the developed systems and the existing accelerator Nuclotron-M into a collider providing at least two beam intersection points. It is planned to complete the Nuclotron-M project in 2011. The physical start-up of the NICA facility is planned for 2015.

To use effectively the NICA collider opportunities, it is necessary to construct adequate detector set-ups at JINR. Such experimental instruments will be **detectors MPD and SPD** at VBLHEP.

The goal of the **MPD** project is experimental studies of strong interactions in hot and dense hadronic matter and a search for a possible formation of the so-called “mixed phase” of such matter. The design concept of the MPD set-up envisages placing the central complex of detecting equipment in the solenoid magnetic field as well as two forward-backward detectors. Under the MPD project, the DLNP is planning to take responsibility for the construction of a compact high-performance electromagnetic calorimeter (EMC).

The **SPD** facility is being developed at VBLHEP for realization of the second part of the scientific programme for the NICA collider concerning investigations of the interactions of colliding light-ion beams and polarized proton and deuteron beams. This will allow setting up spin physics experiments to continue the JINR research programme in this area at a brand new level.

The successful achievement of the goal, set before VBLHEP, for the construction of the **NICA** accelerator complex and **MPD** and **SPD** detectors requires concentration of essential resources and optimization/minimization of financing for another projects carried out in the Laboratory within the existing JINR obligations.

Funding (k$)[*]

Activities	2010	2011	2012	2013	2014	2015	2016
Nuclotron+NICA	10 900	25 100	26 700	26 300	6 200	6 600	8 200
Detector MPD	2 100	4 600	8 100	7 600	5 100	650	650
Detector SPD	130	550	750	850	1 050	1 600	2 700
Experiments with Nuclotron beams	165	175	175	175	155	125	90
Physics of neutrino and rare processes	800	1 300	1 800	2 300	2 300	2 300	2 300
Experiments at external accelerators	2 300	2 450	2 450	2 500	3 200	3 700	3 700
Total	**16 395**	**34 175**	**39 975**	**39 725**	**18 005**	**14 975**	**17 640**

[*] Figures hereinafter do not include personnel, electricity and infrastructure costs.

Nuclear Physics

In line with the JINR Road Map, the following main trends of research in the field of low-energy nuclear physics will be preserved and further developed in 2010–2016: synthesis and study of the physical and chemical properties of superheavy elements using heavy ions, basic research with neutrons, and applied investigations.

The unique opportunities of the JINR heavy-ion accelerators and experimental set-ups have lead to creation of wide international collaborations with research centres of the JINR Member States and with laboratories in other countries oriented on carrying out experiments in Dubna.

1. Experiments at FLNR accelerators

Synthesis and study of properties of superheavy elements

In 2010–2016, efforts will be focused on further, more detailed study of the already opened isotopes of superheavy elements and also on the search for new methods of synthesis of heavier elements. Significant attention will be given to the synthesis of the element with Z=117. Experiments both to study nuclear properties of new isotopes and chemical properties of superheavy elements with Z=111, 113 and possibly with 115 and 117 are planned.

Study of characteristics of spontaneous and induced nuclear fission

Mechanisms of the formation and decay of heavy and superheavy nuclei in reactions with heavy ions will be investigated at the spectrometers which allow scientists to study mass-energy distributions of fission fragments, pre-equilibrium, pre- and post scission neutrons, and also multiplicities and energy of γ-quanta.

Mass and nuclear spectroscopy of isotopes of heavy and transfermium elements

For precision measurements of the masses of these elements and for the study of their physical and chemical properties, the MASHA separator will be used on the beam of the modernized cyclotron U400M. The realization of the project GABRIELA on α-, β- and γ-spectroscopy of transfermium isotopes will be pursued.

Study of mechanisms of reactions with stable and radioactive nuclei

Regular experiments with accelerated ions of radioactive isotopes, produced at the DRIBs (Dubna Radioactive Ion Beams) complex, started in December 2004. These experiments will be continued using instrumentation equipped with cryogenic targets and multiparametric detection systems.

For a full-scale realization of the scientific plans, the DRIBs-III project has been prepared which includes modernization of the existing accelerators and experimental installations, construction of highly effective, new-generation experimental set-ups, creation of new experimental areas and of a universal accelerator for producing high-intensity beams of ions both of stable and radioactive isotopes.

2. Accelerator complex DRIBs-III

The purpose of the project is extension of the suite of accelerated ions, both of stable and radioactive isotopes, and an essential increase of the intensity and quality of beams.

Realization of the DRIBs-III project envisions:

- completion of the modernization of the U400 and U400M cyclotrons
- construction of a new experimental hall
- creation of new-generation experimental set-ups
- construction of a high-intensity universal accelerator of heavy ions.

3. Construction of a new FLNR experimental hall

Construction of a new experimental hall with an area of 2500 $м^2$ is planned. It will be used for work with beams of radioactive and exotic nuclei and for placing new experimental set-ups, including those from other research centres.

Funding (k$)

Activities	2010	2011	2012	2013	2014	2015	2016
Modernization of the existing heavy-ion accelerators:							
building of complete set of equipment and manufacturing of U400R systems	2 000						
installation, adjustment of systems, launching of U400R		1 000					
Support of running experiments	1 000	1 000	1 000	1 000	1 000	1 000	1 000
Construction of a new FLNR experimental hall:							
technical requirements, project	1 000						
civil work		5 000	5 000				
gallery, beam lines				2 000			
Development and creation of next-generation long-acting experimental set-ups:							
physical and chemical separators, systems for collecting and transport of nuclear reaction products, radiochemical laboratory of II class, etc.	1 000	3 000	2 000	2 000	3 000	2 000	2 000
Construction of a high-intensity heavy-ion accelerator ($A \leq 100$, $E \leq 10$ MeV·A, $I \geq 10$ pμA):							
technical requirements, project		1 000					
manufacturing			3 000	6 000	10 000		
installation, beam lines, launching					2 000		
Total	**5 000**	**11 000**	**11 000**	**11 000**	**16 000**	**3 000**	**3 000**

4. Next-generation experimental set-ups

The Flerov Laboratory has begun work to design the following experimental set-ups:

- Universal gas-filled separator for the synthesis of SHE and study of their properties
- Cryogenic detector for studying chemical properties of SHE
- Pre-separator for radiochemical and mass spectrometry research
- Systems for collecting and producing single-charged ions in gas media (gas catcher) for mass spectrometry and for producing RIBs
- Radiochemical laboratory, II class
- Separator of radioactive neutron-rich nuclei for RIB production

– Universal spectrometer for studying reactions induced by RIBs
– Wide-aperture spectrometer of spontaneous and induced fission fragments
– Electromagnetic separator for studying reactions with RIBs
– Prompt-neutron detection system for the DRIBs complex
– Gamma-quanta detectors.

These projects have a high degree of maturity, and their realization can start within 1–3 months after taking decisions to finance them.

5. Construction of a high-intensity accelerator of heavy ions

The new accelerator will significantly increase the potential of the existing accelerator complex of FLNR and will deliver high-intensity beams of accelerated heavy ions of mean masses to the physics instruments in the Laboratory's new experimental hall. Based on the performed analysis, the cyclic type of the new accelerator — the DC200 cyclotron — has been selected. The technical specifications and requirements have been prepared for the new facility, and its designing has started. The new cyclotron will provide acceleration of ions from carbon to xenon up to the energies of 5–10 MeV/n with stepwise and smooth variation. For ions with masses $A<100$, the beam intensity should be at least $5\cdot10^{13}$ 1/s.

Thus, the modernization of the existing accelerators (U400, U400M) and construction of the new cyclic accelerator will create a possibility for conducting experiments with accelerated ions from deuterium to uranium in a broad energy range.

Realization of the research programme of the Flerov Laboratory of Nuclear Reactions for the period 2010–2016, based on the accelerator complex DRIBs-III, will allow the Laboratory to widen the spectrum of the research topics to be addressed and to synthesize new superheavy elements. It will also enable JINR to keep its leading position in nuclear research with heavy ions of low and intermediate energies in the nearest 25–30 years.

6. Nuclear physics with neutrons

JINR's traditional research activities in the field of nuclear physics with neutrons will be carried out at a new level due to the high resolution of the new neutron source IREN, which at the same time will be developed. The main task of the **IREN first stage development** is to reach the designed parameters of the LUE-200 electron accelerator and to provide reliable and stable operation for experimental studies.

Schedule of IREN development

2009: start of two-shift operation with electron beam power 1.4 kW (50 Hz frequency, pulse width 200 ns, average energy of electrons 50 MeV, peak current 2.8 A, neutron yield 10^{12} s^{-1}).

2010: upgrade of the RF power system with new klystron. This will result in RF power increase and duplicate electron energy with neutron yield $3\cdot10^{12}\cdot s^{-1}$.

2011–2012: further upgrade of the RF power system and starting operation with the second accelerating section. This will provide the designed 200 MeV electron energy and beam power about 5.5 kW with neutron yield about $7\cdot10^{12}$ s^{-1}.

2012–2015: upgrade of the klystron modulators in order to reach the designed value of the repetition rate — 150 Hz. Design and construction of a uranium non-multiplying target. Reaching of the beam power at the level of 10–15 kW and neutron yield at the level of several units of 10^{13} s^{-1}, which will position IREN facility in line with the most intense resonance neutron sources of such type.

Funding (k$)

Activities	2010	2011	2012	2013	2014	2015	2016
Maintenance and operation	70	130	200	250	350	350	400
Upgrade of the RF power system	200						
Upgrade of the RF power system, assembling of the second modulator and accelerating section		320	100				
Upgrade of the modulators, design and construction of the non-multiplying U target			360	670	670	580	400
Development of the facility systems, experimental and engineering infrastructure	70	180	220	200	250	300	730
Total	**340**	**630**	**880**	**1 120**	**1 270**	**1 230**	**1 530**

Experiments with neutrons

Experiments will be also carried out at the IBR-2 reactor, mainly those that require high neutron fluxes, at the EG-5 set-up — experiments with fast neutrons, low-background measurements and applied studies, and at external neutron sources.

The research work will be performed in three main directions:

(1) fundamental studies of neutron-induced nuclear reactions,

(2) investigations of fundamental properties of the neutron and UCN physics, and

(3) applied research.

(1) Fundamental studies of neutron-induced nuclear reactions

Carrying out of the first experiments at IREN	2009
Precise measurement of the weak interaction constant in experiments on P-violation. Determination of the asymmetry coefficient at the level of 10^{-8}	2012
Search for rare fission modes. Determination of probabilities of exotic decay modes	2013–2014
Measurements of total, partial and differential cross sections of (n,p), (n,α) reactions for various isotopes	2010–2016
Search for neutron resonances with different structure of wave functions, for various isotopes	2012–2016
Search for a singlet deuteron state. Determination of its lifetime or setting the upper limit	2012
Obtaining of nuclear data for reactor and construction materials	2012–2016

(2) Investigations of fundamental properties of the neutron, and UCN physics

Direct measurement of the n-n scattering amplitude with accuracy 5–10%	2012
Investigation of the effect of accelerated matter, in particular in experiments with giant acceleration 10^5 g	2013
Verification of the weak equivalence principle for the neutron with accuracy of 10^{-4} at the first stage and 10^{-5} in the future	2014–2016
Measurement of double differential scattering cross sections of UCN and VCN at nanostructures. Development of a new type of UCN sources	2015–2016
Measurement of n,e-scattering length using new methods. Determination of the n,e-scattering length with accuracy ~ 2–3%	2012

(3) Applied research

Construction of the detector system for gamma activation analysis at IREN. Performing the experiments	2010/ 2011–2016
Construction of the test bench for applied research at IREN. Experiments on isotope production	2010/ 2011–2016
Performing the biomonitoring of different regions of Russia and JINR Member States using neutron activation analysis; analysis of new materials, surfaces, and food quality; biometric studies	2010–2016

Funding (k$)

Activities	2010	2011	2012	2013	2014	2015	2016
Fundamental studies of neutron-induced nuclear reactions	35	80	125	170	185	255	280
Investigations of fundamental properties of the neutron, and UCN physics	45	80	90	95	95	100	155
Applied research	65	110	155	210	255	275	315
Total	**145**	**270**	**370**	**475**	**535**	**630**	**750**

Condensed Matter Physics

Current trends in the development of scientific research dictate the necessity of an interdisciplinary approach to addressing scientific problems with the use of complementary nuclear physics methods. JINR possesses a unique experimental base (the pulsed research reactor IBR-2, the FLNR accelerator complex, and the Nuclotron) and a wealth of experience in theoretical studies accumulated at BLTP. This allows the Institute to conduct advanced fundamental and applied research in condensed matter physics and related fields — biology, medicine, materials science, geophysics, engineering diagnostics — aimed at probing the structure and properties of nanosystems, new materials, and biological objects, and at developing new electronic, bio- and information nanotechnologies.

1. Research fields

Nanosystems and nanotechnology

Study of nanosystems by neutron scattering methods. Neutron methods of investigation of matter make it possible to obtain detailed information about the atomic and magnetic structure and dynamics of materials at the atomic (micro-) and supra-atomic (nano-) levels. The main research directions are the following: magnetism of layered nanostructures; nanodiagnostics of magnetic colloid systems in volume and interface, of carbon nanomaterials, and of polymer nanodispersion materials aimed at the definition of their structure characteristics at the nanolevel and their role in the formation of physical properties; formulation of recommendations for the development and production of nanostructures and their application in nanotechnology; studies of the nanostructure and properties of lipid membranes and lipid complexes, of the supramolecular structure and functional characteristics of protein biological macromolecules, DNA, RNA, and of the structure of lipid-protein complexes. In view of the commissioning of the CARS microscope, studies of DNA and vibrational spectra of proteins are envisioned.

Experimental and theoretical studies in the field of radiation-ion technology. Accelerated heavy ions are a unique instrument for research in the radiation physics of solid matter. A significant advantage of accelerated heavy ions is their high defect-forming capability allowing, within a short time, the creation of radiation defect density in materials which is comparable with the density obtained at neutron irradiation during several years. An important feature of the use of heavy ions is an opportunity both to modify macroscopic properties of materials and to develop nanosize structures in them. The main areas of research are the studies of the effect produced by multicharged ions with energies from ~ 1 keV/n to ~ 10 MeV/n on materials aimed at modification of their nanostructure, tests of radiation resistance, and targeted modification of properties; synthesis of nanoobjects with unique properties to be applied in electronics, optics, telecommunications, measurement technology, etc; studies of the properties of micro- and nanopores produced by the ion track method in various materials to develop elements of nanofluid technology, to create molecular sensors, and to model biological membranes; development of new promising materials based on secondary structures produced on track membranes by metallization, plasma processing, plasmochemical grafting, impregnations (controlled semipermeable membranes — gates, light-emitting diode matrices, anisotropic optical filters, X-ray radiation filters, etc.).

Detectors for investigation of nanostructures and new materials. Development of the GaAs-based gamma detectors for nanostructure investigations, micro-pixel avalanche photodiodes and their application in nanoindustry, investigation of nanomaterials by positron-annihilation spectroscopy methods and synthesis of photon crystals on the basis of dioxide silicon nanoparticles.

Theoretical studies of nanostructures. The main directions of research are the studies of electronic, thermal and transport characteristics of various modern nanomaterials and nanostructures.

Radiobiological research

Cancer treatment with proton beams. The project has three stages. The first is the development of the method of conformal cancer treatment at the DLNP Phasotron, education of personnel and certification of proton therapy for the use in Russia and other countries. The second stage is oriented towards the construction (in collaboration with IBA, Belgium) of a special medical cyclotron for cancer treatment. The last stage is the proton therapy technology and equipment transfer to the Russian Proton Therapy Centre (at Dubna or elsewhere) with a capacity of 1000 patients per year.

Investigation of mechanisms of the genetic action induced by accelerated multicharged ions. Studies of regularities and mechanisms of formation and repair of DNA damages in human cells. Studies of heavy-ion action on the chromosomal mechanism in human cells. Mutagenic effect of LET radiation on cells of various organisms.

Studies of the action of heavy particles on the ocular structure: the lens and retina. The main purpose of the proposed research will be simulation *in vivo* and *in vitro* conditions of the molecular mechanisms of the origin of the lens-form opacity (cataract) in humans exposed to heavy-ion irradiation.

Studies of regularities of biological effects of accelerated heavy ions on the central nervous system. The main purpose of the planned research on this subject will be studies of morphological, cytological, molecular, and physiological damage in the central nervous system structures, and of the modification of behavioral functions in irradiated animals.

Mathematical simulation of biophysical systems. Elaboration of mathematical models is planned of the induced mutation process in pro- and eukaryote cells at the action of radiation with different physical characteristics. It is planned to use the molecular dynamics methods in the simulation of the 11-cys retinal rhodopsin chromatophore and the surrounding amino acid residue in the chromatophore area at the physiological regeneration of the visual pigment.

New materials

Studies of new materials by neutron scattering methods. The main areas of research include studies of crystalline and magnetic structures of new functional materials, nano- and macrostructures of magnetic semiconductors, atomic dynamics of materials by neutron scattering methods, analysis of the interrelation between the peculiarities of their structure and physical properties.

Theoretical research of new materials. The planned programme of theoretical research will be mainly focused on the analysis of new materials with strong electron correlation that assumes studies of new cooperative phenomena, new types of ordering, magnetism in low-dimension systems and quantum critical phenomena. Theoretical research in this field will be directed to the support of experimental studies of these materials by neutron scattering.

Engineering diagnostics. Earth sciences

The main areas of research are determination of internal stresses in bulk materials and products, studies of the texture and properties of minerals and rocks.

2. Expected results

Nanosystems and nanotechnology

Determination of the depth distribution of magnetization in layered nanostructures, analysis of the influence of proximity effects on magnetic properties. Formulation of recommendations for the design and creation of nanostructures for the use in elements of nanoelectronics.

Definition of structural parameters and mechanisms of stabilization of magnetic colloidal systems, carbon nanomaterials, and identification of the relationship between the structure of the investigated systems and their physical and chemical properties.

Investigation of interparticle interactions and clusterization of magnetic colloidal systems in various types of liquid and solid media. Determination of quantitative and functional characteristics of new polymers.

Analysis of nanostructural modification, targeted modification of the change of properties and radiation resistance of materials under the influence of multicharged ions, synthesis of solids with unique properties for applications in electronics, optics, communications equipment, measuring equipment, etc.

Development of theoretical models to describe electronic and thermal transport characteristics of nanosystems, in particular carbon nanotubes.

Obtaining of information about transport properties of asymmetric electrically charged track nanopores; obtaining of data on the properties of composite track membranes with controlled selectivity.

Development of new types of track nanomembranes (including under innovative projects).

Characterization of the nanostructure of a model lipid matrix of the upper layer of human skin, definition of the role of individual ceramides in the formation of its diffusion properties.

Characterization of the diffusion process of pharmaceutical solutions through model lipid matrices. Definition of structural and functional characteristics of biological macromolecules.

Radiobiological research

Detection of molecular disorders in DNA of human cells under the action of heavy charged particles and structural damage to the chromosome apparatus; analysis of genetic control of induced mutation in cells with different levels of genome organization.

Formulation of recommendations on the threshold doses of charged particles that can cause damage to the lens, retina, and of methods of prevention of eye diseases.

Development of mathematical models of mutation process in cells of pro- and eukaryotes induced by radiation of different quality, modeling of structures of biologically important macromolecules.

Synthesis of new radioisotopes for medical applications.

New materials

Determination of the crystal and magnetic structures and physical properties at the nanolevel in complex oxides of transition metals, multiferroics.

Determination of peculiarities of the molecular dynamics and parameters of the crystalline structure of bioactive materials.

Identification of structural characteristics of materials for the future use in hydrogen power and solid-state fuel elements; analysis of the phonon mode behaviour in reactor materials.

Construction of theoretical models of mutual influence of the electronic structure, magnetic and transport properties of complex systems.

Obtaining of data on peculiarities of the synthesis in metals of multicomponent monodisperse nanophases in the process of low-dose heavy-ion irradiation.

Engineering diagnostics. Earth sciences

Definition of internal stresses in geological materials (texture, deformation), bulk materials, and products for nuclear science and technology.

Definition of internal stresses in industrial materials and products. Identification of rock instability patterns to develop awareness of processes in earthquake foci.

3. Experimental and methodological base

Neutron scattering research

The reconstruction of the IBR-2 reactor— the main basic facility at JINR for neutron research in the field of condensed matter physics, with world-level parameters and the only one of this kind in the JINR Member States, — will be completed during 2010. Research with spectrometers at the reactor involves a user programme based on requests from scientists of Member States to conduct experiments. The work on the physical and power start-up of the reactor with a complex of thermal and cold moderators will be carried out in stages:

1. Physical start-up and beginning of the power start-up, first physics experiments (with water moderators) — in 2010.

2. Completion of the power start-up — in 2011.

3. Implementation of the complex of cryogenic moderators: moderator for channels 7–11 — in 2010, moderators for channels 2–3 and 4–6 — in 2011.

4. First physics experiments with cryogenic moderators — in 2011–2012.

Plan of work for the period 2010–2016:

1. Bringing of the IBR-2M reactor to the design parameters. Study of the physical characteristics of IBR-2M.

2. Routine exploitation of the reactor and provision of the programme of physics research at extracted neutron beams.

3. Development and operation of the complex of cryogenic moderators. Acquisition and launching of a new refrigeration unit for channels 4–6.

4. Construction of the reserve movable reflector MR-3R.

5. Upgrade of the reactor's technological equipment with expiring service (air heat exchangers, electromagnetic pumps, etc.).

6. Elaboration of the concept of the use of IBR-2M beyond the year 2030.

Programme for the development of the spectrometer complex for IBR-2M:

1. Implementation of projects for construction of new spectrometers: DN-6, GRAINS, FSD, which will significantly expand the area of research at the IBR-2M reactor at the world level.

2. Upgrade of the existing spectrometers: HRFD, DN-2, DN-12, SKAT/EPSILON, YuMO, REMUR, REFLEX, DIN2-PI, NERA-PR aimed at improvement of their technical parameters (intensity, resolution, effect/background ratio).

3. Development of projects for new spectrometers: a small-angle neutron spectrometer and a reflectometer with atomic resolution.

4. Development and testing of new neutron-optical methods for investigations of the structure and dynamics of nanosystems and condensed matter, including the spin-echo and other methods based on the Larmor precession of neutron spin.

5. Upgrade of spectrometer elements, development of new types of neutron detectors and data acquisition systems, development of the network and computing infrastructure.

6. Cryogenic research.

Funding (k$)
Research programmes

Activities	2010	2011	2012	2013	2014	2015	2016
Neutron scattering research	120	120	130	140	140	140	150
Biomedical research using heavy charged particles	118	139	163	193	232	268	335
Research in the theory of condensed matter	46	50	54	59	63	68	72
Total	**284**	**309**	**347**	**392**	**435**	**476**	**557**

Funding (k$)
Experimental and methodological base

Activities	2010	2011	2012	2013	2014	2015	2016
Modernization of the IBR-2M reactor	960	850	855	375			
IBR-2M operation expenses	500	500	500	500	500	900	1 000
Modernization of the IBR-2M physical security system	1 360	150	150	150			
IBR-2M spectrometer complex: projects of construction and upgrade of first-priority spectrometers (DN-6, SKAT/EPSILON, GRAINS)	533	591	662	650	500	400	100
Projects of upgrade of second-priority spectrometers (FSD, REMUR, YuMO, HRFD, DN-2, NERA, DIN2-PI), development of new methods of research				137	426	674	1045
Development and construction of spectrometer elements, detectors and data acquisition systems; development of the network infrastructure	190	280	390	545	630	665	730
Equipment for cold moderators of IBR-2M, upgrade of moderators	35	50	45	80	100	160	200
Development of the LRB infrastructure	171	145	156	175	207	224	243
Total	**3 749**	**2 566**	**2 758**	**2 612**	**2 363**	**3 023**	**3 318**

Radiation-ion technology, radioisotope and radiobiological investigations

The family of heavy-ion accelerators created at FLNR — IC100, U200, U400, U400M — provides ample opportunities for radiation physics and radioisotope studies with ions from boron up to xenon in the energy range 1–20 MeV/A.

The further development of stand-alone accelerators and creation of accelerator complexes for scientific and applied research, also for the industry, is planned. Particularly:

- improvement of IC100 (vacuum system, increase in beam energy and intensity, acceleration of W-ions, etc.)
- realization of mass irradiation of polymeric films at the DC-60 accelerator (Astana)
- launching of the DC-72 cyclotron in the Cyclotron Centre (Bratislava) for applied and medical applications
- construction of an ECR ion source for radiation processing of materials and multi-elemental implantation
- creation of specialized equipment for testing microelectronic chips at U400 beams.

<u>New innovative projects:</u>

- construction of a specialized accelerator for the BETA project — manufacturing of track membranes for cascade blood plasmapheresis (intensity of $5{\cdot}10^{12}\,s^{-1}$, energy of ions 2.4–2.6 MeV/A)
- development of new types of track membranes for medical purposes within the BETA project
- use of the experimental base (primarily, accelerators) within the framework of the collective-access International Nanotechnology Centre at JINR and in projects developed in the Dubna Special Economic Zone.

Radioecological research, ultrapure isotopes:

– Use of the microtron MT-25 (photonuclear reactions) and cyclotron U200 ((α, xn)-reactions) for producing unique isotopes, e.g. ^{178m}Hf, ^{225}Ac, ^{236}Pu, ^{237}Pu.

Activities	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Development of the experimental base for radiation physics and radioisotope research (IC-100, MT-25, U-200) and new innovative projects (DC-60M, DC-72, TM, etc.)	Performance of work under orders and contracts						

Theoretical Physics

Scientists of the Bogoliubov Laboratory of Theoretical Physics (BLTP) have accumulated unique experience of research in several fundamental areas of theoretical physics: quantum field theory and elementary particle physics, nuclear theory, theory of condensed matter and methods of mathematical physics. The studies conducted at BLTP are interdisciplinary; they are directly integrated into international projects with the participation of scientists from major world research centres and are closely coordinated with JINR experimental programmes. With the launching of the research and education project “Dubna International Advanced School of Theoretical Physics” (DIAS-TH) and with the opening of new departments of theoretical physics at the Moscow Institute of Physics and Technology and at the Dubna International University, closely associated with the JINR University Centre, BLTP has considerably increased its role of an international educational centre for young scientists and students.

In the forthcoming years, the efficiency of work in the above-mentioned directions will be enhanced along the lines shown in the corresponding programme sections below. Research is planned to be enhanced in nuclear and particle astrophysics, hadron physics under extreme conditions (in connection with experimental programmes of the NICA/MPD project, current and future experiments at RHIC, LHC and FAIR), lattice QCD calculations. Studies in condensed matter physics will be more directly coordinated with the requirements of modern nanotechnology development.

The table illustrates the financial resources to provide for research in theoretical physics on the following topics: quantum field theory and elementary particle physics, nuclear theory, theory of condensed matter, modern mathematical physics, and the research and education project “DIAS-TH”.

Funding (k$)

2010	2011	2012	2013	2014	2015	2016
370	410	435	460	485	510	530

Quantum field theory and particle physics. The milestones in theoretical research in the field of particle physics will be determined by the physics programmes of major international collaborations (LHC, RHIC, FAIR, K2K, etc.) and those at the JINR basic facilities, primarily, of the NICA/MPD project. Major attention will be paid to precision tests of the Standard Model, new physics beyond the Standard Model, hadron structure and spin physics, phase transitions in hot and dense hadronic matter and mixed quark-hadron phase, heavy flavour physics and hadron spectroscopy, neutrino physics, the dark matter problem, and astrophysical aspects in elementary particle physics.

Nuclear theory. The main direction of nuclear studies at low energies in the coming decade will be studies of the properties of nuclei far from the valley of stability, which is an integral part of the physics programme of the DRIBs project (JINR) and practically all existing and scheduled projects at large facilities in Europe, the USA, and Japan. Theoretical research in this domain of nuclear physics will develop respectively. It is planned to proceed with the elaboration of nuclear structure self-consistent microscopic models with density-dependent effective forces, finite-range effective interactions beyond the mean-field and random phase approximations. Nuclear structure models will be applied to the prediction for the rates of weak processes in stellar matter and other astrophysical problems. In the theory of reactions, collisions of ultracold atoms and molecules in optical and magnetic traps, and fusion reactions in crossing low-energy beams of light nuclei channeled inside a crystal will be investigated. Studies of processes of heavy-ion interactions at intermediate and high energies will be mainly oriented to the NICA/MPD project. Nucleon and nucleus structure functions will be studied using the experimental data obtained at JINR, GSI, JLab, and J-PARC.

Theory of condensed matter. Theoretical research will be focused on the analysis of systems with strong electronic and magnetic correlations (layered cuprates in their normal and superconducting state, transition metal oxides, in particular, magnetoresistive manganites and geometrically frustrated antiferromagnetic spinels, and fullerene clusters and lattices, etc.), which involves studies of novel cooperative phenomena, new forms of order, low-dimensional magnetism, and quantum criticality. Research in this field will be aimed at supporting the experimental studies of these materials conducted at the Frank Laboratory of Neutron Physics. Studies of the electronic, magnetic, thermal and transport characteristics of various nanoscale materials and nanostructures will be the key research direction. Carbon nanostructures are of particular interest.

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 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 integrable systems, quantum groups and noncommutative geometry.

Research and education project "Dubna International Advanced School of Theoretical Physics (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, Dynasty, etc.) and state organizations (BMBF, INFN, CNRS) will be an important prerequisite for the successful implementation of this project.

Information Technologies

An important task for the next seven-year period of activity is the formation of a unified Grid environment of the JINR Member States in which three main levels can be distinguished. The **network level** comprises high-speed backbones and telecommunication links. The **resource level** is formed by highly efficient computing clusters, supercomputers, and data storage systems joined into a unified Grid environment. The **applied level** encompasses sets of research topics the solutions of which have been adapted to the Grid environment and within the framework of corresponding virtual organizations.

The elaboration of the network level of the JINR Grid infrastructure includes development and upgrade of the JINR telecommunication links and local network. In particular, it is planned to increase the bandwidth of the **JINR–Moscow channel** in total up to 720 Gbps. JINR is actively involved in the development of an international segment within the GEANT project that will foster an increase in the bandwidth of the international channels up to 10 Gbps in 2009, with further growth in 2010–2016. The integration of the Grid infrastructures of JINR and its Member States is planned through the high-speed European network GEANT. The development plan for the JINR Local Network (LAN) in the projected period foresees an upgrade of the JINR backbone to a data transfer rate of 10 Gbps, connection to this backbone of all the JINR laboratories, an increase in the performance of the LAN central telecommunication node kernel, an increase of the data transfer rate at the level of the Institute subdivisions up to 1 Gbps and an increase of the LAN protection at the hardware level, etc.

Resource level components	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Growth of CICC computing capacity: CPUkSI2K	2 500	4 000	4 000	7 000	7 000	10 000	10 000
Disk storage increase (TB)	1 200	2 000	2 000	4 000	4 000	8 000	8 000
Increase of mass memory (TB)	500	2 000	2 000	5 000	5 000	10 000	10 000
Setting up of CPGS	Preparation of technical requirements and purchase of equipment	Realization	Maintenance and upgrade				
Primary, information, and application software	Maintenance and upgrade						
Licensing of services, office software	Realization			Maintenance and upgrade			

The kernel of the **resource level** of the JINR information infrastructure consists of the high-efficiency **computing clusters** and of the **data storage systems** of the Central Information and Computing Complex (CICC). The requirements for the LHC experimental data processing and analysis stimulate further increase in the CICC performance and disk space. In order to manage the joint Grid infrastructure, it is planned to set up a **centre of primary Grid services**

(CPGS) that will provide coordinated functioning of geographically distributed resource centres. Specific work to set up CPGS includes preparation of hardware and software basis of CPGS, development of tools for service development, execution of CPGS basic services, standardization of the service of information attendance, opening of a certification centre, connection of resource units of the JINR participating countries, etc. The development of **information and primary software support** of the research and production activity of the Institute to achieve a unified information environment of JINR and its Member States is an indispensable condition.

The **applied level of the JINR Grid-environment** covers the user applications working in a **virtual organization** (VO) environment which comprises both users and owners of computing resources. The virtual organization is a flexible structure that can be formed dynamically and may have a limited lifetime. Instances of VOs working within the WLCG project are those that are involved in the LHC experiments ATLAS, CMS, ALICE, being carried out with the direct participation of JINR. The development of new VOs becomes necessary under maturation of the development of **mathematical methods and tools.** In 2010–2016, work will be continued on the development of mathematical methods for modeling physical processes and analysis of experimental data, on the development of software and computer complexes, etc. Research in the field of quantum information technology is also planned.

The seven-year expenses are given in the table. The funding will be carried out both from the JINR budget resources and under special-purpose financing from the JINR Member States.

Funding (k$)

Activities	2010	2011	2012	2013	2014	2015	2016
External communication links	165	65	85	85	135	135	185
LAN	125	125	225	125	205	205	225
CICC and Grid infrastructure	260	460	390	490	650	670	790
Licensed software	80	80	80	80	100	100	100
Service acquisition and other expenses	17	20	20	40	43	53	64
Total	**647**	**750**	**800**	**820**	**1 133**	**1 163**	**1 364**

Education

The Educational Programme of the JINR University Centre (UC) should be developed in such a way that the issue of providing the Institute with research, engineering and technical staff coming from its Member States is resolved. The most efficient way of achieving this aim is to offer JINR-based Master's programmes. The UC's main aim is to provide conditions for a major growth in the number of students and postgraduates from Member States attending the JINR-based programmes. The proposals for addressing the tasks of the UC are drawn up for the following main fields of its activities.

In the next seven years, the UC plans to coordinate the curricula of the JINR-based departments so as to meet in the best way the demands of the Institute and Member States for highly skilled research and engineering staff. A general database of the courses offered by the JINR-based departments has been created. The contents of the courses have been translated into English, which will allow conditions to be created for attracting students and postgraduates of Member States to the JINR education programmes.

The JINR postgraduate courses have become more attractive lately for students from Member States, and the postgraduate entry contest has grown more intense. These tendencies pose new tasks for the UC, in particular: a 15% increase of JINR postgraduates and the prolongation, in 2011, of the postgraduate licensing; the establishment, jointly with the Plenipotentiaries of the Member States, of a special stipend/grant system for attracting applications to JINR postgraduate studies from these countries; the introduction of a bilateral postgraduate system in which postgraduates would have two supervisors: at JINR and at their home universities in Member States.

The UC activities to disseminate information about the Institute and its achievements will be conducted in the following directions: gradual transition to the holding of practical courses all the year round, taking into account the permanent growth in the number of applications for attending these courses; update and extension of the database of short research projects performed by students during their practical work; continuation of the holding of the traditional International Summer Student Schools on Nuclear Physics Methods and Accelerators in Biology and Medicine in different Member States; and the achievement of an increase in the number of universities in Member States with which agreements on cooperation is concluded.

For the education process to be attractive, it is necessary to create a modern laboratory infrastructure equipped with a number of unique facilities. The main activity concerning infrastructure development will consist in completing the creation of the student laboratory complex located in Building 113 of the DLNP site. Special attention will be paid to the continuous support and update of the UC Internet site as a means of disseminating information about JINR's education capabilities.

The UC works on a permanent basis with most talented school students from Member States. The aim of this work is to encourage the interest of school students in modern science. As part of the optional course of physics, groups of secondary school pupils have weekly classes in the UC's practical laboratory course. The task of the University Centre is to show the students the opportunities of getting education at the JINR-based departments and making a scientific career at the Institute's Laboratories. Jointly with CERN, the UC will annually hold professional advancement courses for physics teachers of profile classes.

One of the UC's functions is offering education programmes that concern training and retraining of JINR engineering and technical staff. In the next seven years, work will be continued to obtain licenses timely from the Moscow Region's Ministry of Education to perform this kind of educational activity.

Development of the Engineering Infrastructure

The engineering infrastructure of JINR is the basis for the operation of the Institute and for the implementation of its scientific programme. It is a complex system of interacting elements of which the most important are the following:

– support of the operation of the JINR basic facilities
– supply of energy resources
– availability of communication and telecommunication means
– safety.

1. Operation of the JINR basic facilities

Currently, the basic facilities of JINR are under a programme of upgrade. The aim of this programme is to develop a modern experimental basis that will be attractive for Member States and the international scientific community. The main directions of this programme are described in the relevant scientific research chapters of the Seven-Year Plan. The upgrades of the basic facilities will bring out the Institute to leading positions in the world as a competitive international centre for nuclear physics and make it even more attractive for young talented scientists from Member States.

2. Supply of energy resources

The main tasks of this subsystem are to provide the Institute with electric energy, heat, cold and hot water, liquid nitrogen, cooling and sewage systems. The development of these systems is implemented by the specialists of the Department of the JINR Chief Power Engineer, as well as in the frames of the upgrading of the JINR basic facilities. It is also worth mentioning JINR's special role in the supplies of electric power, water and heat for local consumers. More than 30% of consumers in the right-bank part of Dubna are using heat supplied by JINR structures, and for electric power and water supplies this figure makes about 50%.

Electricity

The main task of the development of the JINR electric energy supply is to increase its reliability category in order to ensure trouble-free operation of the basic facilities. New transformers will be launched at the two main step-down substations and the corresponding distributing gears will be constructed. It will allow sorting out the basic facilities into separate groups and considerably decrease the risk of hazardous failure of these facilities. Besides, it is planned to obtain additional power supply from the Moscow Canal to increase the reliability of the system.

The provision of stand-by electric supplies is also very important. It will be implemented with installing autonomous generators in the sites that are vitally important to the Institute.

Heat and water

To provide normal conditions for the operation of the Institute, it is necessary to continue work on the reconstruction of the pump-filter station, heat stations, heat and water networks; to replace, according to schedule, the outdated equipment and to automate technological processes. Installing modern equipment and use of blocks for commercial accounting of water and heat consumption will allow a considerable decrease of the Institute's costs on public utilities.

Nitrogen workshop

The main task of the nitrogen workshop of the Department of the JINR Chief Power Engineer is to supply liquid nitrogen to experimental installations and basic facilities. The development of the JINR basic facilities as well as the attraction of outside users will allow more efficient loading of the equipment at the workshop to make nitrogen production more profitable. But the main task for 2010–2013 is to transfer the production to energy-saving facilities.

3. Communication and telecommunication means

To implement successfully the tasks envisioned in the JINR Road Map, it is necessary to develop all means of telecommunications. The development of the information and computing infrastructure, including the trunk line channels and the local network, is described in the corresponding chapters of this Plan.

Telephone communications

At present, the JINR telephone station (ATS-6) operates on the basis of the coordinate station ATSC 100/2000. The station provides service for approximately 5500 subscribers, including nearly 3800 JINR subscribers. The planned conversion of ATS-6 to the digital electronic equipment guarantees a considerable decrease of the operational costs and an increase in service quality, at the expense of the replacement of the analog communications to the digital ones. Besides, the costs of the inter-city and international communications will decrease considerably, at the expense of the IP-telephony technology.

4. Safety

The issues of the safety policy include labour protection, industrial safety, management of natural resources, radiation, nuclear and fire security.

Labour protection, industrial safety, management of natural resources

The major task in labour protection is efficient preventive work to avert labour traumatism and profession-related diseases as well as emergency situations and accidents. To address this task, it is planned:

- to attest working places for labour conditions
- to replace, on scheduled basis, the outdated equipment (weight-lifting mechanisms, vessels operating under pressure, elevators, etc.) at dangerous sites
- to equip the industrial-sanitary laboratory with advanced and efficient measuring devices
- to improve information awareness system of the personnel and to promote the qualification of the leaders and specialists in labour protection, industrial safety and management of natural resources
- to dispose high-toxicity production wastes.

Radiation and nuclear safety

The task to minimize the radiation effect on humans and the environment comprises an increase of safety of the operating and planned nuclear physics facilities and provision of safety in handling nuclear materials (NM) and radioactive substances (RS). Besides, a system of strict registration and control of NM and RS, according to the federal laws, standards and regulations, is vital. To address these tasks, it is planned:

- to further develop the existing system of the individual dosimetry control at the JINR nuclear physics facilities, as well as to establish a system of control of the internal irradiation of the personnel
- to upgrade the existing radiation control systems (RCS), to elaborate new RCS at the radiation-hazardous sites of the Institute
- to purchase a mobile auto-radiological laboratory for efficient radiation reconnaissance
- to purchase equipment for NM and RS transportation and storage
- to develop an automatic system of radiation control for the JINR Central NM Stores
- to provide licensing and metrology for NM and RS accounting and control.

Fire security

The main task to provide fire security at JINR is to establish conditions for efficient precaution measures and fire prevention.

Fire protection of buildings and sites of JINR is organized and implemented by Fire Brigade FB-26 based on an agreement with the Institute. According to this agreement, it is necessary to equip the brigade with machinery and equipment.

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 the automatic fire fighting equipment.

To improve and maintain the proper level of the fire security at the Institute's sites, regular measures are necessary to make the buildings and constructions of JINR meet the established norms of fire security. These measures require adequate financing.

Financing (k$)

Activities	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**Bud-get-ary**	**Non-bud-getary**	**Total**
Electricity supply	1 600	1 600	1 000	100				100	4 200	**4 300**
Heat and water supply	6 900	1 500	1 300	1 300	1 400	1 000	800	2 500	11 700	**14 200**
Telephony	500							500		**500**
Radiation and nuclear safety	300	100	100	100	100	100	200	1 000		**1 000**
Labour protection and industrial safety	300	200	300	300	300	200	200	1 800		**1 800**
Fire security	200	300	200	300	300	400	400	2 100		**2 100**
Total								**8 000**	**15 900**	**23 900**

Innovative Activity

The strategy for the JINR development is determined by the triad “science–education–innovations”. This strategy has been approved by the JINR Committee of Plenipotentiaries, and it meets the interests of transition to innovative economies in the JINR Member States.

The innovative activity programme for 2010–2016 is based on the concept of long-term social and economic development of the Russian Federation, as the host country of the Institute, which is drawn up to the year 2020. Our programme includes a complex of activities which will be carried out in association with state institutes of development of Russia as well as private and state organizations in the JINR Member States. These activities will be targeted at:

1. Efficiency increase in the scientific and educational potential

<u>2010–2016</u>

Expenditure increase for Research and Development; implementation of new types of scientific activity funding (project financing, grants), engagement of private financing for Research and Development.

Employee training in the innovative sphere.

2. Development of the scientific, technical and innovative infrastructure

<u>2010–2016</u>

Participation of JINR’s innovative projects in competitions to receive financing from federal target programmes of the Russian Federation and programmes of the European Union.

<u>2010–2011</u>

Commercialization of the deliverables of scientific research and experimental development; formation of network of small and medium innovative companies.

Establishment of a Nanocentre “Dubna” together with the Russian State Corporation “Rusnano” and other JINR partners. The centre will comprise a Multi-Access Centre, a Center for Technology Transfer, and a Seed Venture Fund.

<u>2010–2012</u>

Partnership with venture companies and funds, engineering and development firms. Financing of business projects at all the stages of innovative cycle.

3. Development of the regional innovative nanotechnological cluster

<u>2010–2016</u>

Completion of formation of full-scale plot of nuclear physical and nanotechnologies in the technological-and-innovative special economic zone.

<u>2011–2013</u>

Establishment of a competitive complex of interrelated high-tech production in the field of nanotechnologies in the territory of Dubna and the region.

<u>2014–2015</u>

Establishment of a Venture Capital Centre in Dubna.

4. Effective integration into the global innovative system

<u>2010–2011</u>

Establishment and management of efficient operation of the International Innovative Nanotechnology Centre for CIS and EU countries in Dubna.

Involvement of Russian scientists, who left abroad, in joint activity, promotion of their participation in innovative projects and teaching work.

<u>2013–2014</u>

JINR’s participation in the delivery of several major projects in the field of nanotechnologies based on a long-term technological prognosis.

2013

Patenting and protection of intellectual property rights in accordance with the international standards.

5. Formation of a new innovative culture

2010–2016

Promotion of science and innovations, in particular by means of advertisement, involvement with leaders of public opinion, distribution of “success stories”, etc.

Assistance in innovative PR promotion — “Science & Innovation Relations”.

Development of specialized studies in innovations at the University “Dubna” and at the JINR University Centre.

Participation in international exhibitions, conferences and forums in the field of innovations.

Changes in the timelines and activities of this part of the Plan for 2010–2016 will depend primarily on macro economic factors influencing the JINR Member States and availability of medium- and long-term investment sources within the framework of private-state partnership.

Human Resources and Social Policy

With a view to increasing the efficiency of the JINR operation, the system of the evaluation and remuneration of labour of scientific and other personnel categories will undergo improvement throughout the next seven-year period. The motivation mechanism for high efficiency in job performance and employee career development will be set up in accordance with the principles applied at major international research centers.

The JINR Plan for 2010–2016 to achieve the set goals includes the following actions:

1. Creation of conditions and mechanism for improving the remuneration system

2010–2016

Increase of the JINR budget and optimization of the budget spending on labor remuneration; increase of the remuneration rate based on the situation in the region and in the scientific research sector.

2010

Application of the "PIN — Personal Information" system to evaluate the scientific, innovative and other types of performance by the JINR employees.

Development and approval of the Regulations for the JINR Remuneration System and Incentives.

Monitoring of the performance efficiency of the JINR subdivisions in accordance with the evaluation system used in the Russian Federation for organizations in the state-run science sector.

2011

Preparation of a new version of the Regulation for the JINR Personnel and its approval by the JINR Committee of Plenipotentiaries.

2011–2012

Development and application of regulatory guidelines and other measures related to the protection and use of the intellectual property created by JINR employees.

2. Enhancement of the efficiency in the existing HR management system

2010–2016

Optimization of the personnel structure and adjustment of the JINR staff schedule to changing environment.

Development of the JINR contract employment system.

Assurance of the special status of the JINR executives in the territory of the Institute's host country.

2010

Promotion of establishment of the JINR Personnel Association.

2011

Work to address issues of state pension provision for the staff from the JINR Member States.

Work to address issues of income taxation for the staff from the JINR Member States.

2012

Setting up of an electronic document circulation system which delivers efficiency and transparency to the administrative services provided to the JINR staff.

2014

Review of performance of the JINR staff.

3. Implementation of social safety net measures provided to the employees

2010–2016

Implementation of a complex of measures to attract and recruit young scientists, engineers and workers.

Supplementary actions to support the JINR long-service employees financially and socially.

2011–2012

Application of the non-state pension provision system to JINR employees.

2013–2014

Establishment of an endowment fund to finance the Institute's social programmes.

4. A special programme entitled "Young Staff at JINR" has been approved within the effort to attract, train and recruit young scientists for the Institute. The programme envisions further development of the financial and social support system for young people and of their education, creation of the environment for professional growth, promotion of their motivation towards scientific research or administrative work.

The action plan under the programme "Young Staff at JINR":

1. Annual analysis of the staffing situation, especially concerning young people.
2. Publication of an updated version of the programme "Young Staff at JINR".
3. Formation of a young staff reserve at JINR subdivisions.
4. Development and implementation of social programmes to improve the quality of life and work conditions of young employees:

– implementation of the system of bonuses and grants for young staff
– construction of residential areas for lease to young staff
– health services, sport programmes, assistance to young families
– development of concessional lending to purchase housing property by young employees

5. Improvement of the existing system to attract and train young reserves of the Institute:

– coordination of the programmes of the JINR University Centre (UC) and laboratories
– PR-campaign: delivering public lectures, organizing scientific tours and presentations
– annual scientific conferences, schools, workshops for young scientists and specialists.

The programme "Young Staff at JINR" envisions financing for the key activities indicated in the table below from the following sources: the JINR budget, the budgets of production subdivisions, and non-budgetary funds.

Financing (k$)

Activities	2010	2011	2012	2013	2014	2015	2016
Efforts to attract active and initiative young people:							
recruitment of young people under the programmes of the JINR UC and Laboratories	50 pers.	60 pers.	60 pers.	70 pers.	70 pers.	80 pers.	80 pers.
PR-campaign: public lectures, scientific tours, presentations	20	25	30	35	40	45	50
Training of highly qualified scientific replacement:							
annual scientific conferences, schools, workshops for young scientists and specialists	20	25	30	35	40	45	50
formation of a young staff reserve (~10 persons/year)	8	10	12	14	16	18	20
Incentives to preserve young scientists and specialists in the JINR staff:							
implementation of the grant system for young scientists (~100 persons/year)	450	540	640	750	900	1 100	1 300
bonuses to young scientists	38	45	57	68	80	100	118
concessional lending to purchase housing property (~25 persons/year), non-budgetary repayable funds	300	370	450	480	560	630	740
construction of residential areas for lease to young staff	10 apartments per year, by cost estimates						
social programmes for young people (~200 persons/year): health service, vouchers, sports, assistance to young families	20	25	30	35	40	45	50
Repayable funds	300	370	450	480	560	630	740
Non-repayable funds	556	670	799	937	1 116	1 353	1 588
Total	**856**	**1 040**	**1 249**	**1 417**	**1 676**	**1 983**	**2 328**

Financial Support

Implementation of the JINR development programme for the period 2010–2016 largely depends on the availability of financial resources and their effective use. The main source of funding for projects is the JINR budget.

The basis for the calculation of resources to be allocated for the development projects of experimental facilities under the next seven-year plan is the budget forecast for the period 2010–2015, adopted by the JINR Committee of Plenipotentiaries, which envisions annual increase of the Institute's budget.

According to this estimate, the total amount of contributions from the Member States for seven years would be $ 993.8 million (Table 1).

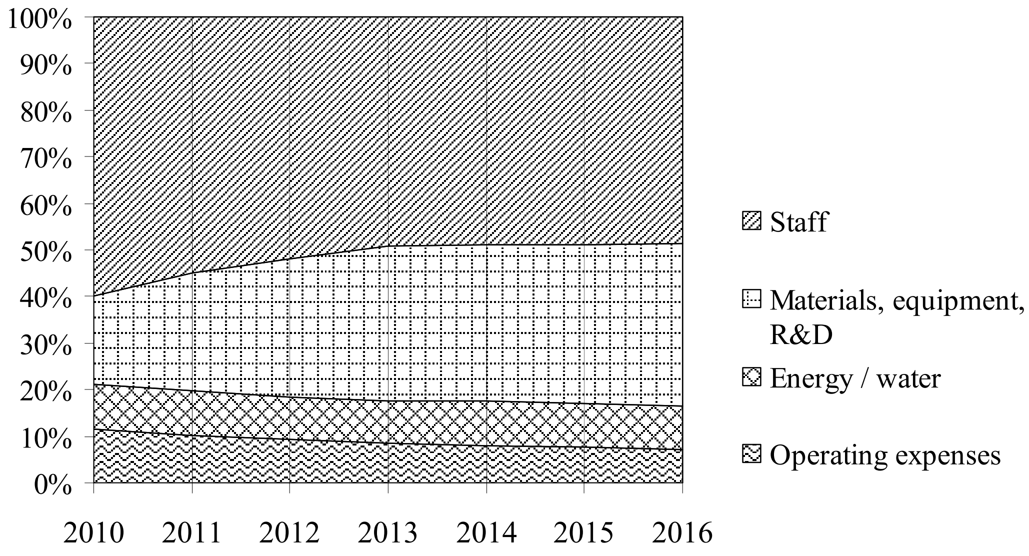
Table 1
(M$)

JINR budget	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**Total**
(without resources received under agreements and protocols on scientific and technological cooperation)	81.2	99.7	118.6	138.8	161.0	183.5	211.0	**993.8**

One of the major areas of financial strategy for the coming years will be a gradual change in proportions of the budget to bring the share of expenditure devoted to the modernization and development of new experimental facilities in the general budget expenditures up to at least 30% (Table 2).

Table 2
(%)

Consolidated budget items	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**Total**
Staff	59.8	55.1	51.9	49.1	48.9	48.8	48.5	**50.7**
Materials, equipment, R&D	18.8	25.3	29.7	33.3	33.4	34.0	35.0	**31.4**
Energy / water	9.9	9.4	9.1	9.0	9.6	9.6	9.3	**9.4**
Operating expenses	11.5	10.2	9.3	8.6	8.1	7.6	7.2	**8.5**
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**



This would bring the total seven-year expenditures by the consolidated budget item "material costs" approximately up to $ 300 million.

Detailed expenses by projects, types of activities and periods are indicated in the scientific research sections of this Plan.

Concerning the priority fields of research and facilities (IBR-2M and spectrometers, the cyclotron complex DRIBs-III, and Nuclotron-M/NICA), the volume of funding would amount to $ 275 million (Table 3).

Table 3
(M$)

IBR-2M and spectrometers	Nuclotron-M/NICA	Cyclotron complex DRIBs-III	Information Technologies	Other projects	**Total**
18.6	148.0	60.7	6.7	41.0	**275.0**

The budgets of the research fields Nuclear Physics, Condensed Matter Physics, and Information Technologies may provide, according to the schedule of activities, the expenditures for the modernization and construction of the experimental base needed for research in these fields. The distribution of resources by the consolidated budget item "material costs" is shown in Table 4.

Table 4
(M$)

Projects	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**Total**
Cyclotron complex	5.1	11.1	11.1	11.1	16.1	3.1	3.1	**60.7**
IBR-2M and spectrometers	2.4	2.4	2.6	2.5	2.4	3.0	3.3	**18.6**
Information Technologies	0.6	0.8	0.8	0.8	1.1	1.2	1.4	**6.7**

Implementation of the project of the NICA accelerator complex and of the MPD detector will require concentration of essential financial resources from the JINR budget as well as involvement of additional investments from non-budgetary sources.

Besides, a deficit totaling $ 37.4 million will occur during 2010–2014, which may be covered by bank loans with repayment from a surplus in 2015–2016 (Table 5).

Table 5
(M$)

Project Nuclotron-M/NICA	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**Total**
Possible funding from the JINR budget	7.5	9.1	17.0	25.8	26.7	29.6	32.3	**148.0**
Requested financing according to the project schedule	9.0	13.6	30.7	36.0	34.2	15.0	9.5	**148.0**
Deficit, surplus	–1.5	–4.5	–13.7	–10.2	–7.5	14.6	22.8	**–**

Funding for other projects includes mainly the support of the project IREN, experiments in the research field Particle Physics and High-Energy Heavy-Ion Physics as well as the costs of the Educational Programme, innovation activity, and the development of the engineering infrastructure (Table 6).

Table 6
(M$)

Other projects	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**Total**
	2.3	3.2	4.7	6.5	7.5	8.4	8.4	**41.0**