Collaboration between the JINR Laboratories

As shown in figure 1 of the Executive Summary, there are 7 laboratories which are the research pillars JINR is based on. In the history of JINR, collaboration between the Laboratories was always a highly important factor for development of new scientific directions and particular projects. Two kinds of interaction between the JINR Laboratories can be noted:

a) Scientists from one laboratory are using experimental possibilities and unique techniques and methods, developed in another laboratory, for their own research.

b) Joint research teams with scientists and engineers from two or more Labs, working together for one experiment.

The analysis of the situation as of today has shown that the exchange of expertise and knowledge between the JINR Laboratories must be strengthened much more for exploiting the richness and resources of JINR, and new structures have to be implemented at JINR, for meeting new challenges of Science and for staying competitive in the World.

In this chapter further details are given on the cross communication between the laboratories complementing the information given in the main chapters of the scientific fields. The summary will point to the necessary steps for meeting the challenges of the future.

Bogoliubov Laboratory of Theoretical Physics

Theoretical investigations at the Bogoliubov Laboratory of Theoretical Physics are always carried out in close coordination with the experimental groups from the other laboratories of JINR. Besides participation in the analysis of the results of current experimental researches, BLTP plays active role in the design and preparation of scientific programs of the future experiments.

The key direction of the planned cooperation between the BLTP and the other laboratories of the JINR is the support and participation in experiments at the JINR basic facilities and at international scientific facilities. Some examples are listed in the following: The theoretical investigations of hot and dense nuclear matter achieved in heavy-ion collisions will be carried out in connection with the development of the NICA facility at VBLHEP. The studies of neutrino properties will be used in the analysis of the Baikal GVD data in coordination with DLNP. Research in the field of nuclear structure and nuclear reactions will be applied for

description of the experimental results expected at the DRIBS-III facility of FLNR. The theoretical advances in the investigation of condensed matter physics and new materials will lead to further improvement of collaboration with FLNP. The developed methods of mathematical modelling can be useful in radiobiological studies at LRB. The need for extensive data analysis will require joint efforts of BLTP and LIT for effective use of existing computing power and implementation of new specific computer architectures.

To summarize, BLTP has strong ties to most laboratories of JINR and is an important asset of JINRs participation in all experiments word-wide.

Laboratory of Information Technology

The major feature of Information Technology today and in the future is the need for its use in all types of the JINR activity, i.e. from the scientific to administrative one. As a result, all work in this field is performed in close cooperation with research groups and their IT specialists from all JINR laboratories and its Member States.

The development and support of the JINR network infrastructure at today's level is of paramount importance and will be solved together with specialists from the JINR subdivisions. Only such mutually beneficial cooperation can ensure the functioning of this complex network infrastructure.

The development of computing is always a response to user requests and the exchange of experience. The joint project with Bogolubov LTP, i.e. the "Govorun" supercomputer, can serve as an example. The operation of the first modification of the "Govorun" supercomputer made it possible to perform resource-intensive calculations in the field of lattice quantum chromodynamics, to increase the efficiency of modelling the dynamics of collisions of relativistic heavy ions, to accelerate the generation and reconstruction of events for the experiments of the NICA project, to calculate radiation safety of the JINR experimental facilities, to significantly speed up studies in the field of radiation biology and other scientific and applied tasks.

Special attention will be given to a close interaction of LIT experts on the data and computing center of JINR with IT specialists working on front-end computing in large scale and data intensive experiments in the different laboratories. JINR will profit from a strong cross- cooperation of these individual IT specialist.

The strategic task to support the concerted cooperation within large-scale projects is the creation of working groups, the complementarity of the knowledge of their members of which covers computing methods, mathematical problems, a deep understanding of

numerical analysis problems, as well as a profound knowledge of the physics side of the problem under consideration.

In light of new challenges related to quantum computing and the application of intelligent cognitive robots for the tasks of JINR and its Member States, the **creation of a research and development group** on the basis of the JINR University Centre to train personnel in this field becomes a promising direction.

To summarize, LIT has strong ties to all JINR laboratories including the administration department by providing service as well as scientific and technical collaboration.

Flerov Laboratory of Nuclear Reactions:

Cooperation of FLNR with other JINR laboratories has a long history and will be obviously continued in the future. At present, it proceeds in the following main directions:

(1) **Use of beams produced by FLNR accelerator complex for needs of the JINR labs.** As an example, FLNR regularly provides beams of heavy ions for Laboratory of radiobiology from the U400M cyclotron. Gamma-quanta and neutron beams produced by the microtron MT-25 equipped with a proper converter are used by DLNP and VBLHEP for testing of radiation hardness of various components of detectors, which are developed, primarily, in the framework of NICA@MPD and JINR-CERN collaborations. Beams of the microtron are utilized as well by DLNP for the purposes of radiation molecular biology studies.

(2) **Cooperation in the field of accelerator science and engineering.** In this respect, one should mention long-term cooperation of groups developing ion sources of ECR (FLNR) and EBIS (VBLHEP) types. It is of high importance for future upgrade of the NICA injection line. FLNR-DLNP collaboration was important for 3D modelling of the main and flat-top dees of the DC-280 cyclotron (SHE Factory). VBLHEP input to the SHE Factory project (beam wobbler for the Dubna Gas-Filled Recoil Separator, DGFRS-2) and production of scanning system for set-up working on electronics testing for radiation hardness (Roscosmos) should be acknowledged.

(3) **Scientific collaboration.** A classic example of scientific cooperation concerns the one between theory and experiment. The FLNR-BLTP fruitful collaboration has a very long history and continues at present in the directions of nuclear reaction studies, nuclear structure, and radioactive decays in the fields of light exotic and superheavy nuclei.

In the direction of nanotechnologies/applied research, FLNR currently collaborates with LRB in developing of perspective materials for burn treatment. Development of track-etched membrane-based sensors for Raman spectroscopy are done with FLNP. There are some other activities at present and many examples in the past.

(4) **IT technologies.** FLNR is one of active users of the LIT JINR high-performance IT infrastructure.

To summarize, the FLNR supporting a user community by providing access to its accelerator beams. The expertise of FLNR in accelerator technologies (ion sources, UHV, beam handling and diagnostics, beam optics) is a great asset of JINR and needs to be made fully accessible to all other accelerator project in JINR. Furthermore, a closer collaboration in the field of sensor/detector development and new digital solutions with other laboratories will benefit the laboratory.

Particle Physics

Dzhelepov Laboratory of Nuclear Problems DLNP and Veksler and Baldin Laboratory of High Energy Physics VBLHEP

Besides the high energy program at the NICA, these laboratories are heavily involved in many international collaborations. There exists a good collaboration atmosphere between DLNP and VBLHEP, and a unique close connection with the Bogoliubov Laboratory of Theoretical Physics. Naturally, both laboratories are well connected with LIT and are even driving the IT development in JINR due to the strong link to the JINR involvement in the LHC experiments ALICE, ATLAS, CMS, where demands on IT is very high.

Since the JINR Particle Physics Program intends to stay well integrated into the European and worldwide Particle Physics Strategies, it must have proper expertise to truly making important contributions to the challenging international collaborations and projects.

This is why it is written in the main chapter of Particle Physics report above, " Yet, a considerable amount of knowledge must be acquired in modern electronics, robotics and precision mechanics. JINR will take all the necessary measures to attract to JINR world-level experts to lead perspective directions within detector technologies".

It should be emphasized that at JINR, like at CERN, users will profit extremely from the presence of a joint micro-electronics group and of detector groups for gaseous and solid-state detectors. They should be open for collaboration with laboratories of JINR member states.

When launched at JINR, such groups or centers of competence must be also at the forefront of technology for detection systems, e.g., for deep underground detectors, for the upgrade of MPD or for the design and construction of SPD detectors at NICA, as well as for the most challenging upgrades of the LHC detectors, and of course also for the R&D for detection systems in the Future Circular Collider FCC. JINR enriched by such centers of competence will be an even more attractive international research facility.

Laboratory of Radiation Biology

Multidisciplinary radiobiological research carried out by the LRB requires strong cross-cooperation between JINR Laboratories. *Accelerator beam-based radiobiological research* is conducted with the help of engineers and technicians of Phasotron at DLNP, U400M cyclotron at FLNR and Nuclotron at VBLHEP. Mutual efforts will be directed to work towards constructing new and upgrading existing *irradiation facilities for radiobiological experiments* with latest state of the art of *detection technologies*. Within the framework of the NICA project, it is planned to continue the LRB's participation in the creation of special station for the irradiation of biological objects at the Nuclotron VBLHEP. Further upgrade will be continued of the LRB's Genom automated irradiation facility at the U400M cyclotron at FLNR. New project of *JINR Biomedical Center for radiation therapy* of oncological diseases will require cooperation of specialists of the JINR Medical technical complex at DLNP and of the LRB. Analysis of nanoscale biological samples (mutant proteins, lipids, etc) is planned at FLNP using *small-angle neutron scattering* technique. In the field of applied materials science, LRB assists FLNR in the development of *perspective materials* for burn treatment. *Supercomputer infrastructure* of LIT is used for numerical simulations in radiation biology with the use of software for molecular dynamics and Monte Carlo codes for particle transport. Within a framework of LIT-LRB joint project it is planned to develop information system for the automated analysis of biological samples using *machine learning technologies*. Involvement of highly qualified specialists of BLTP in radiobiological studies would strengthen the theoretical basis of *mathematical modelling* in this research area. JINR University Center ensures *attraction and education of young specialists* from JINR Member States for their further participation in LRB projects.

To summarize, the LRB is clearly dependent on support from and collaboration with other laboratories. Newly created centers for Sensor/Detector Technologies and for Accelerator Science and Technologies will be instrumental in providing latest state of the art detection

systems and adequate irradiation facilities. In addition, the application of new information technologies in data processing will also benefit the laboratory.

DERICA Project:

The DERICA project is pushing limits on many technologies. It requires the full potential of the accelerator teams of JINR and the best coordinated effort to meet the challenges of the various projects.

The most important cross-laboratory synergy aspects of the DERICA project development are listed here:

(1) The development of the front-end for the LINAC-100 accelerator in the framework of DERICA project is strongly based on the world-class experience of high-intensity ion sources development in JINR Flerov Laboratory (FLNR). The program of the prospective 28 GHz ECR ion source development is recently started in FLNR having in mind operation of the reconstructed U-400 (or U-400R) cyclotron with heavier ion beams, up to U. However, the full potential of such an ion source can be realized as an integral part of the modern linear accelerator.

(2) The development of the low-energy normal-conducting part for the LINAC-100 accelerator and the whole LINAC-30 accelerator in the framework of DERICA project is a natural development of the inter-laboratory and inter-institutional collaboration established during the development of RFQ for injector of light ions LU-20 for NICA project. This collaboration involves the leading accelerator experts both from JINR LHEP and FLNR, Russian institutions (ITEP, MEPhI, BINP, VNIITF, INR RAS), and from leading foreign nuclear physics centers (GSI, LNL-INFN, MSU, etc.). In the framework of the DERICA project the technologies of high-intensity heavy-ion accelerators with high duty cycle (potentially – with continuous wave regime) will be developed.

(3) Superconducting resonators are one of the key components for development of the driver accelerators for several important modern fields: spallation neutron sources, free electron lasers, radioactive ion beam production. The R&D for radio-frequency superconductivity in Russian Federation the last 25 years were stalled. The last 5-7 years these works were reanimated at JINR LHEP in collaboration with MEPhI, PTI

(Minsk), NPI BSU (Minsk). This activity is aiming at prospective superconductivity upgrade of the NICA injector complex. The dedicated scientific research program in the framework of Union State of Russian Federation and Belarus Republic was prepared and is now being finalized. Development of technology of superconducting resonator construction should become the basis for future accelerator projects in Russian Federation and the DERICA project can be foreseen as the next (after NICA) "principle consumer" of this technology.

(4) The beam dump for the intense primary beam at DFS fragment separator of DERICA project is a powerful source of neutrons. They are produced by stopping, for example, 100 AMeV primary Uranium beam in presumably liquid lead or lead-tin eutectics. Neutron flux above $5x10^{14}$ 1/sec can be expected. Being unwanted background within DFS operation, those neutrons can be interesting "product" for studies within scientific program of the JINR Frank Laboratory (FLNP). Scientific opportunities of use of neutrons at DERICA DFS beam dump are under investigation at LNF.

To summarize, this project has been started in collaboration with many laboratories and institutes. A newly created center of competence for Accelerator Science and Technologies is the needed pole of DERICA accelerator project management, guaranteeing drawing of the full potential of JINR.
A newly created center of competence for Sensor/Detector Technologies will be instrumental in providing latest state of the art detection systems for DERICA.

Dubna Neutron Source IV (Frank Laboratory of Neutron Physics of JINR -FLNP)

The planned Dubna neutron source of the fourth generation (DNS-IV) will have significantly higher parameters than at IBR-2 reactor, even be competitive to the European Spallation Source ESS. It will open unprecedented possibilities for scientists from JINR member states and worldwide for research in condensed matter physics, fundamental physics, chemistry, material and life science.

The main project leader is the FLNP with a longstanding experience in reactor operation. FLNP plans to collaborate closely with leading science centres in Russia like A.A. Bochvar All-Russian Scientific Research Institute for Inorganic Materials (VNIINM), or the

Dollezhal Research and Development Institute of Power Engineering (NIKIET). FLNP is well connected to the European neutron science community.

Within JINR, LIT will of course be a collaborator in the design planning of the project as well as in the preparation for modern digital applications like automatization and robotics and AI. The LRB will be a prime-user for radiobiological research.

Conclusion:

There exists in general a good interconnection of the JINR laboratories, collaboration of scientists is existing and working well when motivations are common. There is good collaboration between most laboratories with LIT, some are having their "own" IT experts, which are shielded from other laboratories. The many theorists from BLTP are distributed into the scientific projects of the JINR laboratories, which is a unique situation in the World. Problems have been solved when scientists of two JINR laboratories worked side-by-side in an international experiment, but did not form one single JINR team. But some JINR laboratories have still invisible walls which blocks flow of technical expertise from one laboratory to another laboratory in dire need of that expertise.

These points clearly show that JINR is presently not exploiting its full potential and that it can increase the richness it has today in the individual laboratories by opening the invisible walls surrounding its 7 pillars of science.

There is dire need for collecting all the accelerator know-how of JINR labs in **a center of competence for accelerator science and technology.** In return, the JINR laboratories and the ambitious projects presented in this Long Range Plan will have a much better chance of being realized at the forefront of science.

Furthermore, in order of staying attractive for its member states as a world leading science laboratory, JINR must develop a culture of modern micro-electronics and digital know-how used in state-of-the-art detectors and operation of complex systems. Collaboration with CERN is great, but dependence on another institute is not. JINR needs a **center of competence for gaseous, liquid and solid-state detectors/sensors** and a **competence center for microelectronics and ASIC design.**

Finally, the LIT requests in light of new challenges related to quantum computing, quantum control and the application of intelligent cognitive robots for the tasks of JINR and its Member States, the **creation of a research and development group** on the basis of the JINR University Centre.