NUCLEAR PHYSICS AND ELEMENTARY PARTICLES

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CONCEPT OF THE STATE TARGETED NSC KIPT PROGRAM OF EXPERIMENTAL BASE DEVELOPMENT FOR BASIC AND APPLIED RESEARCH IN NUCLEAR AND HIGH-ENERGY PHYSICS AND PHYSICS OF RADIATION INTERACTION WITH MATTER

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General provisions of the Concept of development of basic and applied research at the Institute of High Energy and Nuclear Physics of the NSC KIPT are presented taking into account contemporary world trends. An analysis of the status and main research directions in Ukraine was carried out, with illuminating general problems, reasons for their occurrence and possible ways for their solution. At present, the main problem is the loss of material, technological and labor resources due to the military aggression of the Russian Federation against Ukraine. Implementation of the main provisions of the proposed concept will restore the research potential of the NSC KIPT as a leading research institution of the National Academy of Sciences (NAS) of Ukraine in the post-war period.

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1. GENERAL PRINCIPLES

The State targeted program of development at the NSC KIPT of instrumentation for basic and applied research in nuclear and high-energy physics agrees with the "Priority directions of science and technology in Ukraine" established by:

- Law of Ukraine, "On the priority directions of science and technology" (№ 2623, July 11, 2001, amended).
- Resolution of the Government of Ukraine "On approval of the priority directions of scientific research and technological developments up to 2021" (№ 942, 07.09.2011, amended).
- Law of Ukraine "On state targeted programs" (№ 912-IX, September 17, 2012 № 912 – IX);
- Order on "Energy strategy of Ukraine for the period up to 2035" approved by the Government of Ukraine (№ 605-р, August 18, 2017).
- Decisions by the Presidium of the NAS of Ukraine, regarding priority and promising areas of scientific research and scientific and technological developments.

2. CURRENT TRENDS IN THE DEVELOPMENT OF NUCLEAR PHYSICS RESEARCH

In 2017, the Nuclear Physics European Collaboration Committee (NuPECC) presented the Long Range Plan 2017 "Perspectives for Nuclear Physics" developed by the European nuclear physics community to specify the development of nuclear physics for the next few decades and the main goals that have to be achieved.

The main goal of the nuclear research is to determine and describe fundamental properties of nuclei based on their building blocks, protons and neutrons.

According to the NuPECC long-term plan, on the way towards this goal, one needs to find solutions for a number of key questions in nuclear physics listed below.

- How are particle masses generated in the quantum chromodynamics, and what are the static and dynamic properties of hadrons?
- How does the strong interaction between nucleons occur in terms of the basic quark-gluon structure?
- What is the limit of the nuclear stability, and where in the Universe are chemical elements created?
- Which properties of nuclei and strong force interacting matter can manifest themselves in cosmic processes and in the structure of stellar objects?

Nuclei are unique objects for fundamental research in physics, and in many cases these studies complement the physics of elementary particles. In addition, the knowledge and technological advances in the fundamental nuclear physics are of great practical importance for the wide application of research results in nuclear energy, industry and medicine, solving problems of safety and proliferation and disposal of nuclear materials, and for the training of highly qualified scientific and engineering professionals.

The NuPECC document specifies five key areas of nuclear physics research and a long-term plan for their implementation, as well as possible practical applications that will be the focus of major efforts and resources in the coming decades. Those are:

- properties of strongly interacting matter at extreme conditions – temperature and baryonic density;
- structure and dynamics of the nucleus;
- nuclear astrophysics;
- symmetries and fundamental interactions;
- practical applications and social progress.

The plan is to maintain existing facilities and launch new ones. Particular emphasis is given to development of nuclear theory and methods for calculating characteristics of nuclei and nuclear reactions, as well as training the next generation of experts in the nuclear science.

3. IDENTIFICATION OF PROBLEMS TO BE SOLVED STATUS AND MAIN FIELDS OF RESEARCH AT THE NSC KIPT

Since the mid-1960s, the main KIPT experimental facilities for research in nuclear physics, radiation materials science and radiation technologies have been the LUE-2000 and LUE-300 electron linear accelerators, along with the necessary experimental infrastructure, viz., experimental halls with magnetic spectrometers, various detector systems with associated electronics, equipment for generating photon beams including linearly polarized ones, positron beams, targets of polarized protons etc. The maximum energies of electron beams in these accelerators were 1.8 GeV and 260 MeV, respectively, which made it possible to fulfill major research programs at a contemporary level on intermediate energy nuclear and particle physics, to study phenomena that occur during the interaction of relativistic electrons and positrons with crystals and to perform scientific research in the field of applied physics. A team of highly professional scientific and engineering personnel was formed at the National Science Center "Kharkov Institute of Physics and Technology", and the world-level scientific schools were created and developed, in particular, in the field of:

– photonuclear and polarization experiments using a beam of linearly polarized photons and targets of polarized protons and deuterons;

– interaction of radiation with matter and crystals. (This research was awarded the State Prize of Ukraine in Science and Technology in 2012).

In the beginning of the 1990s, these accelerators were stopped due to the lack of government funding, and so, much of the experimental research was terminated.

The research that is still being performed in the traditional fields of nuclear physics, nuclear astrophysics and interaction of radiation with crystalline structures is based on extremely outdated instrumentation or on experimental material accumulated in earlier years.

It should be noted that the present research level and expertize of the NSC KIPT scientists is still high enough allowing them to participate in research activities within various international collaborations at experimental facilities abroad.

In the early 2000s, employees of the NSC KIPT Institute of High Energy and Nuclear Physics (IHENP) together with their foreign colleagues set up the beam of linearly polarized tagged photons in the MAX Laboratory (Lund, Sweden) for nuclear experiments and studies of interaction of electrons with matter and crystals. In particular, the beam was used to study mechanisms of radiation in the diamond crystal by incident electrons and to carry out measurements on photodisintegration of nuclei with polarized photons.

Then, the Møller polarimeter was developed in the NSC KIPT and put into operation in the experimental Hall A of the Jefferson Lab (Newport News, VA, USA) to measure electron beam polarization. Since then, the polarimeter has been successfully used in many experiments fulfilling the scientific program of the laboratory.

IHENP scientists took part in preparation of the CMS and ALICE experiments at the Large Hadron Collider (LHC) built at CERN. At present, they successfully participate in the CMS data processing. For this purpose, a dedicated computing facility was constructed in the institute. This facility, T2_UA_KIPT, is the only Ukrainian Tier-2 center of the CMS grid infrastructure, and, since LHC startup in late 2009, a high level of its stability and reliability has been provided. IHENP participants of the CMS are included in the author list of all CMS publications on LHC data. In particular, they are co-authors of the discovery of the Higgs boson, which is an outstanding scientific event.

At the NSC KIPT, a source of intense X-rays generated by the interaction of laser radiation with the electron beam has been constructed, and its setting up is currently underway. This facility, called NESTOR, was assumed to generate intense X-rays on the basis of a relatively cheap electron storage ring, with applying a present-day laser equipment. But for starting up this facility and achieve project parameters, necessary to have a modern electron accelerator having electron energy of about 100 MeV.

At present, a new experimental facility, the accelerator-driven neutron source based on the subcritical nuclear assembly, is being commissioned at the NSC KIPT. The research program here addresses peculiarities of energy production with such systems, various experimental studies with neutron beams and isotope production for nuclear medicine.

PROBLEMS ADDRESSED BY THE CONCEPT

From the above, one can conclude that the scope and level of research activities at the NSC KIPT are high enough, and the experimental schools and development potential are still kept. However, negative trends have increased due to the complete lack of funding for upgrades of basic instrumentation over almost three decades.

The existing experimental base significantly limits possibilities for experimental research. As a consequence, the traditional for the institute areas of scientific interest have no prospects for further development.

The absence of a present-day instrumentation and restriction of fields of experimental research make it impossible to train students and young professionals at a due level and boost further their scientific expertise. As a result, the influx of young people to the institute is practically absent.

ORIGINS OF THE PROBLEMS AND NECESSITY OF THEIR SOLUTION

The main origins of the emerged problems are of the financial, economic, organizational and technological nature. To be more precise, the problems have resulted from lack of funding of the science as a whole in Ukraine, lack of state targeted programs for performing research in the fundamental nuclear physics and for teaching young people, low salaries and decline in the prestige of the profession of a scientist.

Termination of research activities in many fields, in its turn, has led to the outflow of active scientists, as well as to the lack of real opportunity for studying and teaching of young professionals focused on work in Ukraine.

These negative trends can be stopped through creating appropriate conditions for fundamental and applied research in the field of nuclear and high energy physics and studies of radiation interaction with matter.

4. PROGRAM OBJECTIVE AND MAIN LINES OF ACTION

The purpose of this Program is to create a contemporary experimental basis, which will become a ground for the national center for nuclear research in Ukraine capable of reaching the world level of scientific research in terms of quality, accuracy and significance of results.

This goal is consistent with the priority direction of the scientific institutions of the NAS of Ukraine of the appropriate profile (Institute for Nuclear Research, Institute of Applied Physics, Institute of Electronic Physics, Institute of Electrophysics and Radiation Technologies), which was reflected in resolution of the Presidium of NAS of Ukraine “On the status and prospects for development of nuclear instrumentation in the NAS of Ukraine” (№ 96, 09.04.2010).

The program supposes participation in joint experiments and projects within international collaborations, as well as training of specialists from Ukraine at international research centers.

Based on the world current trends in the fundamental high energy and nuclear physics and prospects for future developments in the field, we can itemize the main fields of research as follows:

- Participation in experiments at the Large Hadron Collider (LHC) constructed in the European Organization for Nuclear Research (CERN) – processing of data in order to check the Standard model (SM) and search for possible manifestations of "new" physics beyond the SM; regular increase of the T2_UA_KIPT Tier 2 site resources in accordance with the requirements of the CMS experiment, as well as performing physics analysis of data with involving and teaching young professionals. (According to the current CERN long-term planning, LHC operation is supposed to last, at least, up to 2040. So, participation in the LHC experiments provides an opportunity to carry out research activities on the frontiers of particle physics regularly and for a fairly long time).
- Experimental studies of nuclear structure and mechanisms of nuclear reactions, in particular, within the nuclear astrophysics. (According to expert evaluations and trends in contemporary nuclear physics, research in this area will be among those that will be given priority over the coming decades).
- Studies of radiation interaction with amorphous and crystalline structures, as well as nanostructures. (The study of mechanisms of interaction of relativistic particles with crystals and synthetic periodic structures has a practical value, for example, for development of intensive X-ray and gamma sources. An important advantage of these studies is availability of experimental and theoretical schools in Ukraine that could provide a useful interexchange).

The achievement of the Program goals opens possibilities for practical application of research results in the field of nuclear medicine, nuclear energy, nuclear safety and control of fission materials, R&D on detectors and scintillation materials, as well as allows the next generation of nuclear scientists to work systematically in scientific and educational institutions and industry.

5. WAYS OF SOLVING THE PROBLEMS AND PROGRAM IMPLEMENTATION

To achieve the specified goals, it is necessary to develop present-day instrumentation for generating electron and positron beams making it also possible to setup the linearly polarized and monochromatic (tagged) photon beams.

The Concept assumes two stages of the Program fulfillment. The content of the first stage is as follows.

1. Purchase and starting up of an up-to-date electron accelerator consisting of two 125 MeV accelerating sections with possibilities to increase electron energy up to 500 MeV due to beam recirculation. To obtain a positron beam after the first section, a positron converter has to be installed, with the second section being placed in the solenoid. The maximum positron energy for such geometry is 125 MeV.

2. Renovation of instrumentation in NSC KIPT experimental areas exploited in previous years and application of the experience gained before to enable continuation of research activities in:

- studies of interaction of relativistic particles (electrons and positrons) with amorphous and crystalline substances;
- studies of photo(electro-)disintegration of nuclei near the threshold;
- low-energy nuclear astrophysics;
- development of new techniques for material isotopic analysis.

3. Gradual upgrades and development of experimental equipment at an up-to-date level. Promotion of teaching and training of students and young professionals through involvement in active experimental activities.

As a prototype, one can consider the accelerator that was constructed and used in the MAX Lab (Lund, Sweden) as an injector for storage rings MAX-I, II and III.

4. Development of a project for a storage-ring/pulse-stretcher with the maximum electron (positron) beam energy of 500 to 700 MeV (250 to 500 MeV). The ring will provide the beam duty factor close to 100% for experiments in nuclear physics and setting up photon beams. The project will also include development of the photon tagging system, a synchrotron radiation beam line and an inverse Compton scattering channel for fundamental and applied research.

5. Simultaneously with the experimental activities, personnel training should be started.

For the second stage, it is supposed to construct and put into operation the 500 (250) MeV electron (positron) storage-ring/pulse-stretcher and prepare experimental halls supplied with the necessary experimental equipment. This option enables development of a present-day instrumentation with taking into account new technological achievements.

6. EXPECTED PROGRAM OUTCOME

The Program fulfillment will make it possible to get a contemporary and competitive experimental facility that has no analogues in Ukraine for fundamental and applied research in the field of nuclear physics and astrophysics and for studies of radiation interaction with amorphous and crystalline structures. Then, the experience will be gained for carrying out experimental research at the present-day level that will become an educational ground for boosting scientific expertise of specialists.

The facility will be transformed to a national center of Ukraine and also one of the leading institutions for fundamental and applied nuclear physics.

7. ASSESSMENT OF FINANCIAL, TECHNOLOGICAL AND HUMAN RESOURCES REQUIRED TO FULFILL THE PROGRAM

The estimated amount of funding for the Program is 9…10 billion UAH assumed to be performed mainly by the state budget of Ukraine along with donations from the international assistance, enterprises, institutions, citizens and other legal sources.

The total list of expenditures needed for the Program fulfillment and further operation costs, as well as justification of the contributions by funding sources will be specified in the process of development of the design project for the instrumentation to be created.

The annual amount of Program funding is determined by the Government of Ukraine in accordance with the Law on the State Budget of Ukraine for a respective fiscal year and the Program priorities.

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КОНЦЕПЦІЯ ДЕРЖАВНОЇ ЦІЛЬОВОЇ ПРОГРАМИ РОЗВИТКУ ЕКСПЕРИМЕНТАЛЬНОЇ БАЗИ ННЦ ХФТІ ДЛЯ ФУНДАМЕНТАЛЬНИХ І ПРИКЛАДНИХ ДОСЛІДЖЕНЬ В ГАЛУЗІ ЯДЕРНОЇ ФІЗИКИ, ФІЗИКИ ВИСОКИХ ЕНЕРГІЙ ТА ВЗАЄМОДІЇ ВИПРОМІНЮВАННЯ З РЕЧОВИНОЮ

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Представлено загальні положення концепції розвитку фундаментально-прикладних досліджень в Інституті фізики високих енергій та ядерної фізики ННЦ ХФТІ з урахуванням сучасних світових тенденцій. Проведено аналіз стану і основних напрямків досліджень в Україні, визначено загальні проблеми, причини їх виникнення та обґрунтування шляхів їх вирішення. На даний час основною проблемою є втрати матеріально-технічних та трудових ресурсів, спричинені внаслідок військової агресії РФ проти України. Впровадження основних положень запропонованої концепції надасть можливість відновити науково-дослідний потенціал ННЦ ХФТІ як провідної науково-дослідної установи НАН України в післявоєнний період.

КОНЦЕПЦИЯ ГОСУДАРСТВЕННОЙ ЦЕЛЕВОЙ ПРОГРАММЫ РАЗВИТИЯ ЭКСПЕРИМЕНТАЛЬНОЙ БАЗЫ ННЦ ХФТИ ДЛЯ ФУНДАМЕНТАЛЬНЫХ И ПРИКЛАДНЫХ ИССЛЕДОВАНИЙ В ОБЛАСТИ ЯДЕРНОЙ ФИЗИКИ, ФИЗИКИ ВЫСОКИХ ЭНЕРГИЙ И ВЗАИМОДЕЙСТВИЯ ИЗЛУЧЕНИЯ С ВЕЩЕСТВОМ

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Представлены общие положения концепции развития фундаментально-прикладных исследований в Институте физики высоких энергий и ядерной физики ННЦ ХФТИ с учетом современных мировых тенденций. Проведен анализ состояния и основных направлений исследований в Украине, определены общие проблемы, причины их возникновения и обоснования их решения. В настоящее время основной проблемой являются потери материально-технических и трудовых ресурсов вследствие военной агрессии РФ против Украины. Внедрение основных положений предлагаемой концепции позволит восстановить научно-исследовательский потенциал ННЦ ХФТИ как ведущего научно-исследовательского учреждения НАН Украины в послевоенный период.