Research projects of the Mega-science class in Nuclear University

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Abstract. Fundamental research in the field of high energy physics and nuclear physics is carried out at large international experiments with the joint participation of scientific organizations and research universities. This article discusses the features of the participation of a nuclear university in international research projects of the Mega-science class by the example of the National Research Nuclear University MEPhI. MEPhI is actively involved in the development, operation, and modernization of research projects of the Mega-science class, such as LHC, FAIR, NICA, RHIC, ITER, NEVOD. Participation in these megaprojects gives MEPhI an opportunity to gain unique new knowledge for the development of nuclear technologies and nuclear energy, to increase prestige and to gain access to modern high technologies. These issues were discussed at a conference "Personnel training and legal support for the implementation of scientific projects of the Mega-science class" organized by National Research Nuclear University MEPhI and Kutafin Moscow State Law University on June 20-21, 2019. The aim of the Conference is to discuss the policy management issues of implementation of the Mega-science class research projects.

1. Introduction

Let us give a definition of the concept of the set-up of the "Mega-science" class. A unique scientific set-up of the Mega-science class is a world-class complex of scientific equipment and related educational infrastructure, functioning as a whole, created with the involvement of international cooperation in order to obtain scientific results, the achievement of which is impossible at other facilities in the world.

National Research Nuclear University MEPhI has long been actively involved in the creation, operation and modernization of research facilities of the Mega-science class. First of all, these are huge universally recognized complexes:

- Large Hadron Collider LHC at CERN in Geneve, Switzerland
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- FAIR – Facility for Antiproton and Ion Research in Darmstadt, Germany.
- Collider of protons and heavy ions NICA in Dubna, Russia.
• RHIC – Relativistic Heavy Ion Collider, USA.
• The first ITER magnetic confinement plasma physics experiment in nuclear fusion reactor in France.
• The unique set-up NEVOD at the territory of National Research Nuclear University MEPhI.

The further science moves towards understanding the fundamental laws of nature, the more complicated and costly the process of acquiring new knowledge becomes.

There are several legal forms of Mega-science class projects. The broadest prospects for the development of international integration in the field of large research infrastructures are presented by the International Inter-Governmental Organizations (IIGO) of the framework type. The constituent agreements (Memorandum of Association) of such organizations allow the possibility of implementing any infrastructure projects for a particular scientific discipline. The pioneer among such organizations is CERN. Memorandum of Association is the Convention on the Establishment of CERN of July 1, 1953. Among the largest infrastructure activities of CERN is the LHC. The normative basis for the construction of the LHC is the resolution adopted by the CERN Council in 1994 on the approval of the CERN LHC project with funding.

For the construction and use of the ITER reactor, the ITER Specialized International Inter-Governmental Organization (SIIGO) for Thermonuclear Energy was formed.

An alternative to these international organizations is the institution of a national legal entity, established and acting under the legislation of one of them, as a rule, where the corresponding experimental facility will be located. FAIR is an example of such institution. It is GMbH (Limited Liability Company).

On June 20-21, 2019, a scientific conference was held, organized by the National Research Nuclear University "MEPhI" and the Kutafin Moscow State Law University (MSAL) "Personnel training and legal support for the implementation of scientific projects of the Mega-science class".

2. LHC

National Research Nuclear University MEPhI participates in three of four big experiments at LHC, namely ATLAS [1], ALICE [2] and CMS [3]. Figure 1 shows the main detectors of these experiments.

![Figure 1. The main detectors of ATLAS, ALICE and CMS experiments.](image)

ATLAS and CMS are two 'general-purpose' detectors at the LHC. They are looking for any new particles or unknown physics which the LHC's record high energies might allow us to observe for the first time. It might be dark matter or supersymmetric partners of the Standard Model particles or any other effects beyond the Standard Model.

MEPhI has a long experience of successful participation in great international ALICE megaproject at CERN [4-5]. In ALICE, physicists from National Research Nuclear University MEPhI are looking for quark-gluon plasma to study its properties. Modeling of the conditions that took place 10-6 seconds after the Big Bang is being conducted.
3. FAIR

The ultra-modern FAIR [6] accelerator complex being built in Darmstadt (Germany) will provide high-energy, precision-tuned beams of antiprotons and various ions that are 100-1000 times higher in the intensity than currently available beams. More than 250 Candidates and Doctors of Sciences from Russia participate in FAIR. The main goals of the FAIR studies are as follows: the search for new forms of matter, a study of QCD phase diagram, the discovery of new exotic nuclei, fundamental symmetries and ultrahigh electromagnetic fields, super dense plasma, materials science, and radiation biology. The initial version of FAIR costs 1.2 billion Euros. The possibility of increasing the cost of the project to 2 billion Euros through additional contributions is currently being discussed. Russian contribution to the FAIR budget is 17.4%. Figure 2 shows the projected FAIR complex.

![Projected FAIR complex](image_url)

**Figure 2.** Projected FAIR complex.

National Research Nuclear University MEPhI very actively participates in the Compressed Baryonic Matter (CBM) experiment in FAIR project at Darmstadt [7-8]. The scientific program of the CBM experiment includes studies of extreme states of nuclear matter and a phase transition to a quark-gluon plasma at high baryon density in nucleus-nucleus collisions; studies of the structure and leveling of the state of baryonic matter at densities comparable to the density of the nuclei of neutron stars; searching for the boundary between the phases of baryonic and quark-gluon matter, searching for the critical point and signs of the beginning of the restoration of chiral symmetry at high baryon density.

Unlike experiments conducted at the RHIC and LHC colliders, the FAIR CBM experiment will aim to study in detail the properties of matter at the highest baryon density values that can be achieved under terrestrial conditions.

Recently, Ilya Selyuzhenkov, an employee of the National Research Nuclear University MEPhI, was unanimously approved as the coordinator of the physical program of the CBM experiment.

4. NICA

The NICA (Nuclotron based Ion Collider fAcility) [9] superconducting accelerator complex is a new accelerator complex, which is being created on the basis of the Joint Institute for Nuclear Research (Dubna, Russia) in order to study the properties of dense baryonic matter and spin effects in strong...
interactions. One of the main scientific tasks of the Nuclotron-NICA megaproject is the study of the phase diagram of highly compressed baryonic matter in laboratory conditions. Such matter exists only in neutron stars and supernova nuclei. In laboratory conditions, collisions of relativistic heavy ions are used to create matter with high baryon density. The detector systems of experiments BM@N (baryonic matter at the Nuclotron) and MPD (Multipurpose Detector at the NICA collider) are designed for experiments in the field of relativistic nuclear physics at accelerators of the Nuclotron-NICA complex. The scheme of the NICA complex megaproject is shown in figure 3.

![Figure 3. Scheme of the NICA accelerator complex megaproject.](image)

Having many years of experience in participating in experiments on collisions of relativistic heavy ions at the RHIC and LHC colliders, scientists of the National Research Nuclear University MEPhI have been participating in the NICA project from the very beginning of its implementation [10-11]. The events at JINR in April 2018 (visit of a large delegation of MEPhI led by the rector) gave a new positive impetus to the development of cooperation between JINR and National Research Nuclear University MEPhI on the NICA project.

5. RHIC
The RHIC (Relativistic Heavy Ion Collider) [12] is the first and one of only two operating heavy-ion colliders, and the only spin-polarized proton collider ever built. It is located at Brookhaven National Laboratory (BNL), USA. By using RHIC to collide ions traveling at relativistic speeds, physicists study the primordial form of matter that existed in the universe shortly after the Big Bang. There are two detectors continuing to operate at RHIC: STAR and PHENIX. The scheme of the RHIC complex megaproject is shown in figure 4.
STAR is aimed at the detection of hadrons with its system of time projection chambers covering a large solid angle and in a conventionally generated solenoidal magnetic field, while PHENIX is further specialized in detecting rare and electromagnetic particles, using a partial coverage detector system in a superconductively generated axial magnetic field. MEPhI takes part in physics coordination and analysis in STAR, as well as detector R&D, construction and maintaining (laser, gas and video systems, Event Plane Detector), and software developments [Star] [13-14]. In 2018 MEPhI was invited to participate in upgrade of PHENIX detectors. MEPhI began this works from testing new scintillations plates for electron and hadron calorimeters and some new approaches were proposed to improve the construction of future calorimeters.

6. ITER
ITER (International Thermonuclear Experimental Reactor) [15] is an international nuclear fusion research and engineering megaproject, which will be the world's largest magnetic confinement plasma physics experiment. Figure 5 shows an experimental tokamak nuclear fusion reactor that is being built in Provence, southern France.
In 2016, a memorandum of cooperation was signed between National Research Nuclear University MEPhI and the ITER International Organization. The memorandum providing for the development of cooperation in research and training will be carried out in coordination with the National Research Centre “Kurchatov Institute”, which heads thermonuclear research in Russia [16-17].

A thermonuclear reaction occurs without radioactive fuel. Plasma is a source of fast neutrons. Deuterium is pumped in a vacuum, a gas discharge occurs, and plasma is formed. It is heated to 150 million degrees to start a thermonuclear reaction. Achilles heel is a plasma fuel. It strives to cool, and disruption is possible. Runaway electrons can burn through the wall of the reactor. The challenge is the plasma retention.

The budget of the ITER project is $20 billion. Russia contributes 9%. A planned launch date is 2025.

7. NEVOD
NEVOD [18] is an experimental complex fully located at the territory of MEPhI and created by the hands and minds of MEPhI scientists [19-20]. The main tasks of the unique NEVOD installation are:

- Search for new processes and states of matter in nucleus-nucleus interactions.
- Early detection of dangerous magnetospheric and atmospheric phenomena using cosmic ray muons.

The energy range to be covered is very wide: from 1 to $10^{10}$ GeV.

The solid angle to be covered by the NEVOD set-up is $0^\circ < \theta < 180^\circ$ in zenith and $0^\circ < \varphi < 360^\circ$ in azimuth angles. The advantage of the NEVOD experiment compared to similar experiments in the world is in that in addition to vertical cosmic muons (as in other experiments) NEVOD also measures the fluxes of horizontal muons. The appearance of the complex is shown in figure 6.

![Figure 6. The appearance of the experimental complex NEVOD.](image-url)
8. Conclusion
What does National Research Nuclear University MEPhI get from participating in projects of the Mega-science class?
1. By participating in these projects, National Research Nuclear University MEPhI acquires the opportunity to obtain unique new knowledge about the structure and properties of matter necessary for solving the problems of creating scientific and technological bases for nuclear energy of a new generation, as well as expanding the scope of use of nuclear technologies and finding promising ways to use nuclear energy.
2. The position of National Research Nuclear University MEPhI will the strengthens in the international markets of high technologies for high-tech products in the field of atomic energy use and other fields. The prestige of National Research Nuclear University MEPhI will increase.
3. There will be an opportunity to train Russian scientists in conducting research at the forefront of science and at the most advanced scientific equipment.
4. During the construction of the FAIR accelerator complex and the first controlled fusion reactor with magnetic plasma confinement (ITER), National Research Nuclear University MEPhI will receive orders for the development and manufacture of high-tech products, as well as obtain access to foreign high technologies.

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