Megascience class projects maintenance

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Abstract. The paper considers the peculiarities of unique scientific facilities operation (installations of the megascience class), special attention was paid to the activities of the International Center for Neutron Research on the basis of the high-flux research reactor PIK and the prospects for adapting foreign experience to Russian projects. A number of features of organizing access to the results of work on megascience facilities are described. It is shown that there is an access hierarchy structure with the gradual increase of open data impact. The problem of remote access to mega-installations and the organization of the corresponding business processes are considered. The results of the analysis of risks and challenges associated with the organization of work at megascience facilities are described. A number of practical steps have been proposed in order to optimize the use of the outcomes of unique scientific facilities operation. The mechanism of accounting for intellectual property objects is discussed, possible ways of assessing, examining and commercializing the results of scientific research through the cadastre of intellectual property are proposed. It is shown that a number of trends have received additional impetus due to the quarantine regime imposed in connection with the coronavirus infection in 2020.

1. Introduction

The modern scientific landscape is being formed under the influence of both the urgent challenges of modern science and as a response to the ongoing processes of globalization. These two factors impact, in particular, the format of joint scientific research carried out by a consortium of scientists at specialized facilities (research infrastructures, installations of megascience class). From a “scientific” point of view, such an infrastructure is the only possible modern tool capable of solving vital problems and responding to global challenges of our time, providing an opportunity for interdisciplinary research and projects [1,2]. On the other hand, the research carried out on such installations can be characterized as not only unique-like, but as full-cycle scientific work (from fundamental research to applied outcomes [3]). The corresponding scientific facilities are denoted by the term “megascience”.

From a “global” point of view (taking into account the processes of globalization of science and society) projects of the megascience class can also be defined as a scientific “supranational” organization with “independent representations” [4] or, from an institutional viewpoint, as an organizational and managerial innovation [5], financing the creation and operation of which is beyond the capabilities of individual states [6]. At the same time, even in the case of the construction of such facilities by one country independently (for example, the installation of USSR-4 (Specialized Synchrotron Radiation Source SSRS-4)), their practical use goes beyond the capabilities of one state, and already at the planning stage it is supposed to attract scientific teams from other countries in future.
In fact, a megascience class project can be considered as a business project, resulting in a commercially viable installation that has no analogues in the world, or in new (unique) knowledge and technologies that give impetus to the development of new technologies [5,7].

Note that for the Russian Federation, the issue of creating unique scientific facilities is especially relevant in view of the approval in March 2020 of the Federal Scientific and Technical Program for the Development of Synchrotron and Neutron Research and Research Infrastructure for 2019-2027, within the last a number of works are planned to create advanced scientific infrastructure facilities. It is assumed that the active participation of Russia in projects for creating megascience facilities will contribute to the integration of the Russian research and development sector into the global international innovation system [8], and will also lead to an increase in the efficiency of budget spending and the effectiveness of the research and development sector [5].

In general, depending on the scientific problems being solved, the research infrastructure of the megascience class can be implemented either in the form of a set of infrastructural objects localized in one territory (single-sited) or in the form of distributed institutions consolidated in a single network, where each object, in turn, can be regional, national or international [9]. Research infrastructures can be of both physical and virtual nature (e.g., in the form of e-infrastructure). They can include scientific equipment, scientific collections, archives, databases, or any other unique object that can be used for research purposes.

Despite the high role of fundamental scientific works in the general list of areas of activity of megascience class facilities there are noticeable results of their practical implementation. Thus, the industries where research outcomes obtained in megascience class projects using synchrotron sources are in demand are extremely diverse, and are adapted in various sectors of the real economy [10,11]. The use of super-bright X-ray beams in the study of matter allows one to see how very complex systems (e.g., proteins) are arranged, how energy is released in living cells (e.g., the cells of the human brain), thus, for example, it becomes possible to accurately select drugs; to conduct the analysis of the connection between brain synapses of patients in the development of brain diseases.

The studies [7,12] analyze the main problems of the functioning of scientific and technical projects of the megascience class. The most pressing problems, according to the authors of these works, are the customs and visa regimes of the participating countries and the consolidation of intellectual property rights. Besides, in works [7,13-17] the following problems are considered: the form of cooperation; formation of the management organization and its structure; share of funding; distribution of powers between governing bodies; the procedure for the distribution of the rights of participants when making decisions; distribution of property during the liquidation of the project; role of the authorities.

2. Problem formulation

The use of mega-installations involves the solution of many related tasks: from the technical support of the project to its methodological support. Projects of the megascience class must be considered as a complex system, requiring both a specific management apparatus and appropriate legal and information support to ensure its performance.

In this work (carried out with the support of the RFBR grant № 18-29-15015), in order to apply the best practices to ensure the effective use of the International Center for Neutron Research on the basis of the high-flux research reactor PIK, a number of megascience facilities operation features were studied.

First, in terms of organizing access to the results of work on megascience facilities, it is shown that an access hierarchy is being formed, with gradual increase of open data policy performance (within the scientific projects and afterwards).

1 Decree of the Government of the RF of 16.03.2020 № 287 “On Approval of the Federal Scientific and Technical Program for the Development of Synchrotron and Neutron Research and Research Infrastructure for 2019 – 2027”
Secondly, the issue of remote access to the mega-installation is considered. The requirements for the organization of such work became especially relevant during the coronavirus 2020 pandemic. Possible changes in business processes in connection with the implementation of remote access are being discussed.

Third, the risks and challenges associated with the organization of work at megascience facilities were studied. The analysis with regard to Russian realities is given, the table of risks of creation and operation of large research infrastructures and research facilities of the megascience class is compiled.

Fourth, a number of practical steps have been proposed in order to optimize the use of unique scientific installations results. The mechanism of accounting for intellectual property objects created as a result of the use of megascience facilities, possible ways of assessing, examining and commercializing the results of scientific research are discussed.

3. Research outcomes. Access to the results obtained on megascience facilities

The results obtained at megascience facilities are used by scientific teams around the world. The large volume of data, the need for their complex processing, storage and analysis have led to the fact that working with this information has become the most important area of activity within the framework of the megascience project. The collected information after minimal initial processing (“raw data”) was sent for analysis to the data centers of the participants in the mega-installation.

With regard to the data obtained during the work of scientific installations of the megascience class, two approaches can be distinguished. Within the framework of the first one (performed, for example, at the Large Hadron Collider, at CERN) the open data policy is implemented, when the scientific results gained by the collaboration are published and are in the public domain. Open access to raw (unprocessed) data is not expected. The data itself (in the processed format) is stored for a long time and is available for repeated analysis.

The second approach is implemented, in particular, in the European XFEL: all raw data and associated metadata, as well as the results of raw data analysis obtained as a result of private research, would belong exclusively to the client who acquired access and is not subject to the Scientific Data Policy of European XFEL.

The process of producing (obtaining) data at megascience facilities can be summarized as follows. The data from the detectors are transferred to the temporary storage, and the preliminary rejection of the data can be performed. Temporary storage is usually a fast-access system of limited size that must be freed up to receive the next portion of experimental data. Data from temporary storage is moved to permanent storage, while additional data processing may occur (depending on the experiment). The location of the permanent storage is not tied to a specific installation, and can be anywhere in the world. Data moved to persistent storage is processed and analyzed to produce on-site results (without involving specialists from the original megascience facility). At all stages of obtaining and primary processing, (as a rule) only members of a selected team of scientists participating in the experiment or members of the collaboration have access to the data [18].

The organization of these works required optimization of the relevant business processes and taking into account the specifics of remote access in the documents of title. For example, in the case of CERN, the MONARC project (Models of Networked Analysis at Regional Centers for LHC Experiments) was created back in 1998. It yielded in the concept of a hierarchy of data processing, modeling and analysis centers. There are currently 4 tiers of processing centers. At the bottom (zero) level there is the Tier-0 CERN Computing Center, that deals with the primary reconstruction of events, calibration, permanent storage and archiving of the complete set of “raw” and simulated data. Then there are Tier-1 (13 centers), Tier-2 (about 170 centers), and, finally, Tier-3 (about 50 centers), represented by university clusters, or centers that provide resources on a voluntary basis, where physical data analysis is carried out [18,19].

A similar policy for working with data was implemented in the case of the global neutrino network (GNN) [20]. This network can be interpreted as a distributed scientific infrastructure, its elements being separate mega-installations and collaborations (for example, the IceCube collaboration with 47
organizations from 12 countries of Europe, America and Asia or the Dubna deep-sea neutrino telescope of multi-megaton scale).

Thus, in this case, we are talking about the presence of a unique scientific installation (neutrino telescope), on which a wide research program is being implemented in the remote access mode. Also, neutrino telescopes can be viewed as sources of information that is distributed within the network between its participants for further processing.

4. Research outcomes. Remote access to megascience facilities

Working on mega-installations in remote access mode was assumed in most projects from the very beginning, starting from the appearance of the corresponding technical solutions, but the quarantine restrictions accompanying the spread of coronavirus infection in 2020 made the remote access format vital. The pandemic not only demonstrated the extreme relevance of the development of the task of remote access to research and educational infrastructure, but also made it possible to give this access format a completely new functionality - ensuring the health safety of participants in megascience projects.

As our analysis shows, the possibility of conducting scientific work on installations of this class remotely is a specific highly specialized product that is a locomotive for developing mass remote access technologies not only for commercial, but also for social tasks.

The entire life cycle of megascience facility can be divided into 2 related tasks. First, the “engineering” task is the solution of engineering (applied) problems arising during the creation, operation and modernization of the installation (the actual set of scientific equipment). The second, “scientific” task is the solution of scientific and practical challenges, setting up an experiment and analyzing the data obtained (carried out with the help and through the digital infrastructure). As part of the work within the first task, the physical implementation of the experiment and its support (installation, adjustment, repair and commissioning of equipment, maintenance of activities) take place. Activities in the second course can be described as processing of the results (data obtaining, data handling, data mining, etc.).

To solve the first problem, a duty group is present in the proximate vicinity of the installation. This group is responsible for installation operation provision. The range of tasks of this group is limited, and mainly consists in launching and, if necessary, configuring the installation software. That is, this group does not directly physically interfere with the installation itself. The activities of this group can also be carried out remotely. For example, in the international project Borexino, there is an additional independent data collection system based on fast waveform digitizers (FWFD), implemented in Borexino by specialists from the Kurchatov Institute with the aim of expanding the dynamic range of spectrometric measurements of the detector into an area inaccessible to the main electronics up to ~ 60 MeV. The complex allows, among other things, to collect data remotely without the need for scientific teams to travel to the location of the detector.

In the work of all astronomical projects (Square Kilometer Array - SKA, GNN, SETI), the second task is more important and noticeable. Above, using the example of GNN, we have described the principle of distributed data analysis in remote access mode.

It can be seen that remote access is a necessary element of many megascience facilities, and it has become firmly established in scientific practice. In order to optimize scientific work, to maximize the involvement of the scientific community, and commercialize the results, it is proposed to form an e-Infrastructure. In scientific usage, e-Infrastructure is a technological and sociological solution to the problem of efficiently connecting laboratories, data, computers, and people with the goal of enabling derivation of novel scientific theories and knowledge. Digital infrastructure (e.g., data centers), which is an integral part of e-Infrastructure, does not duplicate or replace the “physical” one. It is mostly about the way of organizing modern scientific research [11,21].

It can be seen that the digitalization of scientific research, the high role of remote access to mega-installations and / or to data obtained at unique scientific facilities is a durable trend that has been
implemented for a long time. Its updating in 2020 due to the coronavirus pandemic appears to be only an increase in the already existing trends.

In order to take into account these changes and new requirements, it is necessary to make a number of changes in some business processes and to ensure a more complete account of the specifics of remote access in the title documents.

First, it is necessary to reduce to a minimum the need for the customer's physical presence at the facility where the megascience-class installation is located.

Secondly, it is necessary to develop an appropriate digital infrastructure. This means both the creation of new objects of digital infrastructure (data centers, processing algorithms, etc.), and the integration of megascience facilities into the existing elements of e-Infrastructure.

Thirdly, it is necessary to provide legal and methodological support for the operation of megascience installations in remote access mode. So, to support a remote work format within the framework of a megascience class project, it is necessary to create an appropriate information system (including management and decision-making). Some aspects of creating such a system were considered by us earlier: we took into account socio-economic aspects [22], the need to create a system of information support for the circulation of intellectual property objects [23], the requirements of national security provision [24].

Fourth, it is necessary to cultivate engineering personnel capable to solve the accompanying tasks of maintaining and ensuring the remote access mode.

One of the options for solving this problem is the use of digital twins of existing projects. Currently, the data obtained by computer generated events are already used in conjunction with physical installations at a number of megascience facilities. They are deployed to solve local problems of specific experiments. For example, ATLAS (CERN) uses data obtained by computer generated events (Monte-Carlo [25]) as an auxiliary tool during the “real” experiment.

It is obvious that the creation of a complete digital twin of any project of the megascience class would in itself be a project of the megascience class and would require an infusion of comparable amounts of funds and intellectual activity (the authors suggest using the term UltraTwins or MegaTwins). It is believed that it is possible to attract business to create and support the work of digital twins (this policy would also reduce the associated costs). The formation of a digital twin would also allow solving the problem of providing a remote work format for a larger number of specialists in the scientific and educational sphere. This “democratization” of technology would ensure easy access (including for non-specialists) to knowledge in technology and business without lengthy or expensive training. This policy, called “citizen access”, have gained success in application development, in data and analytics systems, in solving design and knowledge problems [26].

To ensure the continuity of the educational trajectory for students of secondary and higher institutions, it is proposed to use existing game shells with the add-ons creation with the ability to simulate the studied processes (or to stress the most important traits). The possible use of the Minecraft game shell is discussed by experts as the tool to form an idea of the megascience world for society.

5. Research outcomes. Risks of Megascience Projects Implementation

Since a megascience class project is a large and complex system, each stage of the project life cycle is an independent project with its own life cycle, consisting of the following stages: initiation, planning, implementation, monitoring and control, completion [27]. It is clear that any business project is accompanied by risks - both obvious and hidden. And the challenge is to identify these risks in relation to the overall project life cycle.

A very limited number of scientific publications are devoted to the topic of risk analysis of the creation and operation of large research infrastructures. Risk issues for specific infrastructure projects are considered in the preparation of the Conceptual Design Report (CDR) and the Technical Design Report (TDR) of each specific project and are not the subject of scientific research.
Among the works devoted to the issues of risks and problems of implementation of research infrastructure projects, it is necessary to note scientific publications [28-31], which provide an overview of the preliminary risk analysis of the Russian-Italian IGNITOR project and a number of technological risks of the ITER (International Thermonuclear Experimental Reactor) project. The article [32] considers the issues of creating the Super Charm – Tau Factory project, Russia. The papers [10,33-35] consider the problems and provide an analysis of the risks of research infrastructure projects from the point of view of financial and economic support.

A number of works [36-38] are devoted to a review of the methodology for assessing risks of infrastructure projects regardless of the subject area of the object: the impact of risks on the implementation of the infrastructure project schedule is studied, methodologies for risk management at infrastructure facilities are considered, and a comparative analysis of risk management methods for large infrastructure facilities is carried out.

We have undertaken a comprehensive systematic analysis of risk models for the following megascience projects, and large research infrastructures: LHC (Large Hadron Collider), ESRF (European Synchrotron Radiation Facility), European XFEL (European x-ray free electron laser), ITER, Ignitor, BNL (Brookhaven National Laboratory), RIKEN, SKA (Square Kilometer Array), LNGS (Laboratori Nazionali del Gran Sasso), ESS (European Spallation Source), etc. We draw the list of generalized categories of risks that are necessary for a comprehensive analysis in the implementation of research infrastructure projects and formulated the minimum required set of actions for submission solutions to minimize the consequences of potential problems [39].

Despite the successful participation of Russian organizations in the construction and operation of foreign facilities of the megascience class, a number of negative aspects can be identified that must be taken into account when designing and analyzing the structure of risks for the creation and operation of unique scientific research facilities in the territory of the Russian Federation [33,40]. The main negative factor in terms of international cooperation in the creation of scientific infrastructure facilities is the lack of activity on the part of foreign partners in participating in Russian scientific infrastructure projects. This situation adds up for a number of reasons, which include:

- poor predictability of political and financial support for Russian infrastructures;
- excessive bureaucratization of international scientific and technical cooperation in comparison with leading foreign research institutes and laboratories;
- lack of social infrastructure of European level in scientific domestic organizations and shortcomings of its planning in projected projects.

In general, the analysis of the design and operation processes of both domestic and foreign research infrastructures makes it possible to single out the following categories of risks that are necessary for consideration within the framework of a full-fledged system analysis:

- political risks;
- economic risks;
- target risks;
- technical and technological risks;
- risks of implementing the research program;
- risks associated with the safety of the population and the environment;
- unpredictable risks.

Our analysis shows that due to the uniqueness of each created or managed scientific infrastructure, potential risks cannot be unified and must be considered in each case individually. Flexibility and an individual approach to the assessment of each stage of the implementation of megascience facilities
would minimize risks and significantly reduce costs. The main results of our study [39] are given in the table of risks for megascience projects implementation (table 1).

Table 1. Risks of the creation and operation of large research infrastructures and research facilities of the megascience class.

| Risk category                          | Risks events                                      | Risk mitigation methods                                                                 |
|----------------------------------------|---------------------------------------------------|----------------------------------------------------------------------------------------|
| Political risks                        | Project implementation under sanctions             | Conclusion of intergovernmental agreements                                             |
|                                        | Changing political priorities                     | Minimization of the time interval for the transition to the stage of project implementation |
| Economic risks                         | Excess cost of project implementation              | Continuous interaction with authorities                                               |
|                                        | High inflation                                     | Administrative and technological measures aimed at reducing the cost of the project       |
|                                        | Economic crisis (in the country participating in the project and global) | Joint activities aimed at reducing the influence of the inflation factor                |
| Target risks                           | Insufficient development of the theoretical base of the subject area of research | Preparation of alternative technological and technical solutions                         |
| Technical and technological risks      | Inability to achieve the specified technical parameters | Comparative analysis of projects that have the closest characteristics or similar tasks and subject areas of research |
| Risks of implementation of the research program | Impact of political, economic and technological risks | Reanalysis and adjustment of theoretical justification at an intermediate stage          |
| Risks related to public safety and the environment | Risks of emergency situations of emergency situations for the population and the environment | Detailed analysis of potential technical and technological solutions of the project at the stage of TDR development |
| Unpredictable risks                    | Emergency (technological) situation; force majeure  | Re-analysis and adjustment of technical and technological solutions of the project at an intermediate stage |

In this paper, we do not consider such a problem as the legal regulation of the activities of megascience facilities and the associated risks and challenges.

6. Research outcomes. Proposals for optimizing the use of the results of the work of unique scientific installations

As mentioned above, the results of the work of mega-installations are in demand in various branches of human activity (see, for example, [11,24,41]). The purpose of the development of the Russian innovation system is to increase the global competitiveness of Russia\(^2\), and, first of all, to form a market for legal regulations of the intellectual activity. At present, it is planned to create a set of measures to protect intellectual property and reorient government customers to purchase science-

\(^2\) Order of the Government of the RF of 17.11.2008 № 1663-r (as amended on 28.09.2018) “On the Concept of long-term socio-economic development of the Russian Federation for the period up to 2020”
intensive and innovative products for the real economy based on Russian technologies. An indicator of the positive dynamics of such development may be the growth in the number of patents, allowing Russia to take by 2024 the 5th place in the number of world patent applications.

Based on the results of the analysis, we propose to use the INPRO (intellectual property) cadastre as a base for the information support system for intellectual property turnover. This element of the innovative infrastructure is virtual in nature (as a component of e-Infrastructure), and is a systematized, formally compiled on the basis of periodic or continuous observations, a set of basic information (register) about the economic and intellectual resources of the project (internal and external) [23,42].

The INPRO inventory should reflect:

- main characteristics of the INPRO facility, the value of rights to the INPRO facility;
- all transactions with INPRO with an indication of the copyright holders and assignees, the volume and cost of the assignment of rights to INPRO, the turnover of rights to the INPRO object;
- facilities intended to renovate, including innovation solutions (e.g., innovation triades) created in the process of development;
- purchase and sale of rights to INPRO facilities with an indication of the volume, including but not limited to purchase of limited licenses (e.g., real estate lease accounting), citation and other use of INPRO, other market transactions with INPRO;
- use of INPRO objects in the production of new INPRO objects in the form of objects of industrial property, objects of copyright and related rights;
- support of the INPRO object throughout its life cycle from registration of the appearance of the INPRO object to the withdrawal of the INPRO object from the sphere of economic turnover.

The INPRO cadastre should support the work of users located at geographically remote sites; contribute to the formation of a single economic space for innovation, build an ecosystem of innovations. In practice, the INPRO cadastre could play the role of an intellectual property market, a “meeting point” for the creator and consumer of innovative products.

It seems that the unified INPRO cadastre of the Russian Federation should include cadastres at the level of an organization, a group of enterprises and facilities of regions and subjects of the Federation. For adequate operation, it will be necessary to use GRID computing technologies and ensure the availability of backup data centers throughout the Russian Federation. Data on INPRO facilities provided to users of the INPRO cadastre will be issued in the form of an INPRO cadastral map provided at the request of cadastre users.

The authors believe that the creation of the INPRO cadastre would contribute to the following positive shifts in the functioning of the Russian innovation system.

Firstly, market accounting of rights to INPRO objects of intellectual workers in the education and science system, design, expert, analytical organizations, management and production structures of enterprises, institutions, organizations, regardless of departmental affiliation, would be implemented.

Secondly, more accurate (objective) accounting and recording of the contribution of workers (including scientific, educational, expert, design, management organizations and institutions) to the creation of the final product would be organized.

Thirdly, a barrier would be erected on the way of the unscrupulous “shadow” use of INPRO in the production of new intellectual scientific-theoretical, scientific-practical and scientific-methodological results.

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3 Passport of the national project “Science” (approved by the Presidium of the Council under the President of the RF for Strategic Development and National Projects (Minutes of 24.12.2018 № 16))
We believe that the INPRO cadastre would allow to quantify the transformation of innovation into a leading factor of economic growth in all sectors of the economy and can serve as a basis for comparative research.

In the future, it is possible to talk about the alignment of the INPRO cadastre of the Russian Federation with similar databases of other countries.

7. Conclusions
At present, most states understand the importance of science for the society development. Mega-science projects based on international cooperation are actively being created in the world for fundamental research in various fields. The peculiarities of the work of such projects and the experience of international scientific cooperation lead to the emergence of a number of peculiarities in the regulation of such issues as the distribution of risks, financing, responsibility, etc. to overcome global challenges, including the development of methods to prevent the spread of pandemics based on genetic research.

In this work, we have considered some features of the operation of mega-installations. In general, the current prospects in the use of megascience facilities continue the previous scenarios, and the coronavirus pandemic only acted as a catalyst for the existing trends.

Our analysis shows that digital content will become a mandatory element of any mega-installation: its mandatory inclusion in the digital infrastructure (if earlier as an addition to the real one, now - as its integral part). Megascience facilities are now unthinkable without their digital twin(s). This process will be accompanied by the strengthening of the role of e-Infrastructure (as a single system connecting physical objects and the virtual layer) as a response to current challenges.

A high degree of interconnectedness and inclusion will lead to the formation of a new super-infrastructure. It is expected that the basis of such a structure could be elements of the scientific infrastructures of ESFRI in the EU and a global network in the Russian Federation.

The risks and challenges associated with the organization of work at mega-installations have been studied. The corresponding is given with regard to Russian realities. Awareness of current trends, risks and threats associated with digitalization must be accompanied by an understanding that society (represented by the state) sets the rules and regulations for business, and not vice versa. The reason for such policy is rooted in the fact that only the government (the country as a whole) is able to ensure the order, implementation and functioning of projects of the megascience class. That is why it becomes socially necessary to form a well-thought-out and effective system of regulation by means of the law of relations between man, science, state, society and nature. And although the policy of prohibitions and restrictions seems to be the simplest solution to the problems that arise, this approach proves not to be effective as desired. In the applied aspect, it is possible that part of such a system of future regulation would belong to the newly formed complex branch of law - scientific research law (the law of science) [43].

We have proposed a number of practical steps to optimize the use of the results of work on megascience facilities. The idea of creating an intellectual property cadastre (INPRO cadastre) has been discussed, it being designed to become both a tool for accounting and examination and a “meeting place” and / or “an intellectual property market”.

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