EDITORIAL

A Policy of Anticipation¹ as a Strategic Objective of Space Biology and Medicine at the Present Stage

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Abstract—This article reflects the ongoing debates in Russia regarding paths of innovative development and the role that fundamental science has played in the development of technology critical for national security and for its breakthrough potential. Alternative routes of technical development include variations in priority support for those points of growth, in which Russia has attained and steadily held the leading position, occupying a prominent place in the international division of labor. Russia's space program is a good example of the successful implementation of a national program and provides a demonstration of the country's leadership role in this area of human activities. This article presents an analysis of the factors and circumstances in Russia that predetermined, in the early, "Gagarin" period of piloted space flights, its winning of the leading position. They also determined the vector of the development of manned space flight for many years to come. Even taking into account the host of issues with the implementation of the International Space Station (ISS) utilization program and the planning of manned flights to the Moon and Mars, the unique experience of preparations and the conducting of research and tests with humans in space—the enormous groundwork in fundamental biomedical research over the past 50 years of piloted flights—provides the basis for an optimistic prognosis for gaining headway with essentially new, ambitious space projects. The key question is whether the proactive strategy of prioritized development and the affirmation of the role of manned space flights as the most integrated and science-intensive sector of innovative achievement will be realized. The development of the space industry depends upon the answer, not only at the present stage but in the long-term as well, as does the fate of the national fundamental space sciences, an integral part of which is space biomedicine.

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Russian space programs, despite the objective difficulties and problems, support the real possibility of maintaining the country's leading position in this sphere of high technologies in the coming decade. The maintenance of the status of a country that possesses unique space-based technologies, including technologies based on fundamental advances in space biology and medicine, requires the development of a clear research strategy and a continuous enhancement of efforts aimed at its implementation. The maintenance of such a high status cannot be the result of a passive following in the footsteps of the world's process. The use of terms such as "maintain par," "achieve a level of," and "close the gap," often used in the context of the expected medium- and long-term development trends in Russian science, is not fully justified in those sectors of science and technology in which leadership has already been reached and/or in which there is advanced groundwork relative to the global level. In this case, a simple "alignment" for partners and/or competitors in practice means reducing Russia's own

pace of development and loss of initiative. We believe that, in these circumstances, is more appropriate to use the term "anticipation," which we interpret as an active influence on the development of science, dictated by the realization of the higher needs of society and the consolidation of the best national traditions and scientific achievements. With this approach, emphasis is placed on the promotion of new technologies, which determine the ability of countries and societies to confront global challenges and threats. They simultaneously make it possible to follow the internal logic of the development of science itself and to retain the most viable "growth points," the loss of which would lead to its degradation [44, 45, 49, 50].

The selection of the term "anticipation" from many synonymous terms ("prediction," "forecast," "prevention," etc.) and including it to the title of the publication most closely reflects and captures the difficult though emblematic situation in choosing a strategy for the development of biological science in the interests of space exploration. The features of this strategy, which were objectively formed sometime before the first space flight of our compatriot Yuri Gagarin, can clearly be distinguished today.

At present, the scientific community faces a sharp question: to what extent does the basic state of funda-

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¹ Monolingual dictionaries give the following semantic variants of the original Russian term "uprezhdenie": (1) advance of someone; (2) (outdated) warning, advance notice; (3) location ahead; (4) anticipation as action; (5) corresponds to Russian "pred" in synonyms of "preduprezhdenie" warning.

mental science, with biomedical research as its component, affect the possibilities for the promotion of innovative projects of manned space flights (SFs)? It is impossible to answer this question without referring to its origins, to the very beginning of the era of manned space exploration, without any attempt to assign historical priorities.

A Brief Excursus to the History: to the Anniversary of Yuri Gagarin's Flight

On April 12, 1961, one of the main events of the twentieth century took place—the first human flight into space, featuring our compatriot Yuri Gagarin. The fiftieth anniversary of the event will be celebrated in Russia on the state level, and the entirety of 2011 has been proclaimed the Year of the Russian Cosmonautics² [42].

Today, it is fully understood that this historic achievement, which is attributed to the heights of scientific and technological achievements of the twentieth century, was been primed (and “anticipated”) by the favorable combination of many national and state factors and conditions [7, 25, 34, 44, 48]. The latter include the scientific prediction of the historic significance of the breakthrough into space, made by Russian thinkers, philosophers, and mathematicians (K.E. Tsiolkovskii, N.I. Kibal'chich, F.A. Tsander, Yu.V. Kondratyuk, and the forerunner of modern space ecology and anthropoecology V.I. Vernadskii); support for the idea of space flights in 1950–1960s by the leadership and eminent members of the Russian Academy of Sciences (M.V. Keldysh and his associates and followers); the flowering in the post-war years of the talent of the chief designers of the country's rocket and space technology (Korolev and his associates and followers); the fantastic commitment of all the participants of the space project (from the cosmonautics rank and file workers to the cosmonauts of the first, “Gagarin's” team; and the triumph of the national school of aerospace medicine (O.G. Gazenko, A.M. Gening, V.I. Yazdovskii, etc.), which was based on the outstanding achievements of the Hall of Fame of Russian scientists in various fields of biology and medicine. L.A. Orbeli, V.V. Strel'tsov, N.M. Dobrotvorskii, A.P. Apollonov, N.M. Sisakyan, A.V. Lebedinskii, V.V. Parin, and V.N. Chernigovskii—these names form an incomplete series of brilliant scientists and representatives of unique schools of Soviet science.

A retrospective look at the history of manned space flights shows that the timely efforts of Soviet researchers resulted in all the necessary conditions for the preservation of life, health, and efficiency of cosmonauts in the first flights. But for these achievements, the pace of development of the entire space industry would have been totally different, much more modest. A signifi-

cant factor ensuring the unconditional leading role of Russia at the first stages of the “space odyssey” was the implementation, in the era preceding space flights, of high-altitude and supersonic jet aircraft flights, as well as the creation in our country of an advanced scientific school for aviation physiology and medicine [6–9]. According to O.G. Gazenko, a unique feature of space medicine is that it was formed as a special branch of the theory and practice of medicine even before the first manned flight into space [6, 7]. During this period of time, the advances of aviation medicine in the field of high-altitude and long-term flights on airplanes, as well as the results of biological experiments in high-altitude rockets and the first artificial satellites of the Earth performed in 1951–1961, have become landmark achievements [11, 48, 49]. These facts, historically recognized and appreciated by the international community, are examples of scientific anticipation of the highest standard [8, 12, 14–16, 23–27, 48].

Manned Flights and the Human Factor

When highlighting the major factors and conditions as well as the threats and risks that significantly affect the dynamics of events and have long-term consequences for every single branch of production, transport, science, education, etc., and for the entire strategy of the economic development of the state, it is necessary first of all to focus on the state of basic scientific research, including all those sectors that are directly related to the human factor. It is generally recognized that only significant achievements in basic research can give a qualitatively new impetus to the development and introduction of advanced technologies. The degree to which different fields of basic science are represented and developed determines the potential of any country in the world. For this reason, the substantiation of promising directions in scientific research, including biomedical studies, is the focus of the attention of experts in the field of space exploration and is an important step in predicting its development [1, 8, 9, 17, 25–27, 28–30].

Both in Russia and the United States, intensive work on developing national strategic plans for the research and exploration of space by humans has been carried out in recent years. According to the “Basic Policy of the Russian Federation in the Field of Space Activities for the Period until 2020 and Beyond,” one of the main goals of the strategic policy in this area is the creation of scientific, technical, and technological conditions for the implementation of large-scale space projects providing in-depth research and exploration of celestial bodies and the formation of stable international relations, including those in the interests of manned SFs. The Federal Space Program of Russia for the period of 2006–2015 expressly postulates the necessity to create the groundwork for a manned flight to Mars.

² Order of the Government of the Russian Federation no. 410-r dated March 31, 2009.

The position of United States, one of the leaders in the manned space flights, is also sufficiently indicative in terms of strong support for space activity.

On June 28, 2010 the government of United States published a document entitled “National Space Policy,” which sets out the main directions of national policy reform in the field of space activities [32].

This document states, in particular, that sustainable development and the stability of space activities, as well as free access to space and its unobstructed use, are vital aspects to the national interest for the United States. It was also stated that a responsible approach to the sharing of space on the basis of openness and transparency of space activities meets the interests of all countries. This approach will contribute to the prevention of significant controversy and would eliminate erroneous assessment of the actions of partners and mutual distrust. In this regard, it is planned to expand international cooperation in the field of the peaceful use of space, as well as to ensure the safety of SFs by conducting operations aimed at eliminating collisions in orbits and reducing the pollution of space by fragments of rockets and destroyed spacecraft.

One of the main objectives of the space policy of the United States is the need to expand and ensure human activities within the solar system. For this purpose, the possibility of implementation of manned spacecraft flights beyond Earth's orbit is considered.

The above document of the United States also affirms an important principle for the choice of the development strategy for space technology. It postulates that any country aspiring to leadership in the modern world should not fall behind in the areas related to the national security, which determine the development of transportation and information infrastructure, global space communications, and space monitoring. To meet this postulate, it is necessary to possess key or critical technologies.

The “List of Critical Technologies” in which, in the opinion of the leading scientists of RAS, Russia, maintains a leading position, includes the technologies of life support and human body protection, which is closely linked with the objectives of Russian space activities [17, 31, 33–35, 38–40, 49].

The ability of any country to launch space vehicles and implement manned SFs de facto ushers the particular country into the group of the most technologically advanced nations. However, forecasting critical technologies is most difficult, because it cannot be boiled down to the search for individual points of “break-throughs” or “gaps” in one or another individual item of scientific knowledge. Instead, it must lead to the formulation of a more important issue, namely, whether it is possible to develop a fundamentally new quality of national research within the forecasted period and to ensure its integration within the framework of one or more ideas and projects that are really crucial for the country's future [17, 27, 39, 40, 43, 44].

Today, under the conditions of globalization, the program of human exploration of near-Earth space, the moon, and the nearest planets completely meets these criteria [1, 13, 21, 22, 25, 28].

Although this position has been accepted and approved by the majority of Russian experts, it calls for a discussion about specific paths to the progressive development of space research. A number of scientists, including academicians B.E. Chertok and E.M. Galimov, propose various alternative variants of the strategy of space research and development [5, 10, 25]. The existence of controversial issues is confirmed by discrepancies in the scientific community, including the Russian Academy of Sciences, regarding the overall assessment of the effectiveness of the scientific research in space carried out to date [34]. However, there is no doubt that the implementation of manned SFs is impossible without medical support of the maintenance of health and effectivity of spacecraft crews [13, 19, 20, 37, 46]. In this regard, many alternative variants of the realization of the space program should be supported by advancing in-depth studies of the problem of the safety and protection of the crews of manned space objects (MSOs), which will fly in orbits other than the near-Earth orbits, taking into account the duration and intended use of MSOs [10, 13, 16, 52].

As for future SF crews, the essence of the emerging new biomedical problems can be understood from the standpoint of the analysis of the risks that will accompany the crews of promising MSOs, risks that have only been studied to a certain extent in the current missions. Which new factors and health risks will be encountered in long-term missions to other planets?

Studies and tests performed in Russia show the need for increased efforts in studying the following most anticipated risks [3, 4, 15, 19, 20, 27, 46, 47–49, 50]:

(1) Genetic and metabolic risks in long-term flights due to substantially different levels of exposure to physical factors compared to the Earth:

- long-term microgravity and hypokinesia;
- direct effect of variations in the solar wind and galactic cosmic radiation, not transformed by the Earth's magnetosphere;
- attenuation, up to the absence, of the magnetic field of the Earth;
- alternation of gravity of different levels;
- Increased level of cosmic radiation outside the Earth's radiation belts.

(2) Risks of adverse dynamics of the mental state and deterioration of the efficiency of crew members due to:

- the full autonomy of flight of an expeditionary complex;
- the long-term stay of the crew in social isolation, limited space, and separation from the familiar terrestrial conditions of life;

—the limitation of informational support and the obtaining of instructions in the context of unexpected problem situations;

—the need to develop new directions in activities that have not previously been provided in the training of the crew and that require additional special training equipment, including directed training of the body and correction of its functional state;

—a high degree of responsibility for the mission's success in a climate of awareness of significant risk;

—the difficulties in interpersonal communication under conditions of long-term isolation, with unexpected sources of social conflicts and changes in the mental status.

(3) The risk of diseases due to the low level of technically and technologically possible medical support in severe health disturbances, difficulties in remote medical diagnosis, insufficient knowledge of the specific course of a number of diseases and the specific effects of the conventionally used drugs under conditions of SF, the lack of onboard technology for replacement therapy, surgical and microsurgical intervention, cell therapy, etc.

(4) Physiological and hygienic risks of long-term stay in a changed gas atmosphere, possible risks associated with the degradation products of interior work materials entering into the atmosphere of a confined space object, and the change in the composition of materials under the influence of various physical factors of SF.

From a technical point of view, the development of manned space flight programs should be primarily ensured by the following: increased durability of equipment, increased maintainability, the ability to perform equipment repair by the crew, replenishment of consumables, the implementation of activities in open space, and the provision of safety and life activity of crews (i.e., an actual increase in the quantity and quality of onboard resources, which can be actively used based on the abilities of the crew and the qualifications of larger crews of MSOs [18, 41].

Many future manned missions are characterized by certain common features in the assessment of the role of the human factor. Primary activities include (1) extravehicular activity and the implementation of repair and installation-commissioning works inside and outside the MSO; (2) the long-term technical maintenance of support systems, including the propulsion systems (nuclear reactors in particular), technical control of the safety of the living conditions of the crew onboard the MSO, control of the state of degradable materials from which the MSO is made; and (3) the visual task of monitoring the situation outside the MSO [25, 34, 41].

Today, the possibility and even the necessity to use human capabilities for building, repair, and maintenance of large and very sophisticated constructions in

space is almost proven. Man in space will be in demand as a builder, installer, and repairer.

An example of this type of activity is the successful use of the technology of the extravehicular human activity on the repair of autonomous spacecraft and sophisticated devices such as the Hubble space telescope [25, 51]. It should be noted that it was Russian scientists who created the groundwork in the development of extravehicular human activity technologies, ranging from the design of the means for protection and rescue to the methods for the prompt medical monitoring and biomedical training of humans. The use of these techniques made it possible to obtain in the future a number of brilliant practical results in terms of flight safety and the reliability of extravehicular human activity.

Long-term prospects are also characteristic of research and testing activity of crew members. Test and research cosmonauts working with sophisticated space equipment often demonstrated their undoubted advantages in performing those experiments and activities that cannot be fully automated and they preliminarily planned to the last detail.

The Development of New Biomedical Technologies for Manned Spaceflight Support

Space biology and medicine, as an independent and advanced field of scientific knowledge integrating a set of biomedical research and technologies, studies the interaction of living systems with all factors of SF and space [8, 15, 23, 24, 48].

The development of manned vehicles for deep space exploration will require solving a wide range of innovative biomedical, technical, and technological problems of space biology and medicine that did not arise during the creation and operation of the near-Earth manned stations.

To date, the results of surveys served for the development and successful use of a set of tools and methods of biomedical support of manned missions in low near-Earth orbits, carried out under the protection of the Earth's magnetosphere. The main objectives of improving biomedical support of manned SFs, according to the ideas of the leading Russian scientists [6–9, 11–15], are:

—Development of criteria for medical and psychological screening and training of crews for flights, improvement of the work permit requirements for persons with partial failure of health.

—Creation of reliable and ergonomic space suits and life support backup systems.

—Development of improved methods for preventing the adverse effects of long-term exposure to microgravity.

—Ensuring radiation safety at all stages of mission.

—Health support for the development and tests of promising manned space equipment and its components.

—Improving the ergonomics of workplaces, equipment, and the means of life support of humans in MSOs.

—Solving the problems of planetary quarantine.

—Medical and technical support for the development of advanced MSOs.

—Implementation from ground-based and flight programs of basic and applied biomedical research on the mechanisms of adaptation of living systems to the conditions and factors of SFs.

—Improvement of the health care system based on the latest technologies and advances in medical science and technology.

—Development of international cooperation in the implementation of current and future projects in space exploration.

To further space exploration, including the preparation to interplanetary flights, it is necessary to develop and test the technologies to ensure a longer stay of humans in microgravity while maintaining a high level of health and performance. The International Space Station has a unique basis for solving these problems [1, 18, 41–44].

Analysis of the scientific and technical problems of the Russian strategy for future human space exploration, proceeding from the basic provisions of the Federal Space Program of the Russian Federation for 2006–2015 [49], shows that many of the problems are closely related to space biology and medicine. Namely, these are the long-term, autonomous stay of crew members in deep space; effective radiation protection of crew members; establishment of the health, efficiency, and safety of crew members at all stages of flight; comfort of living conditions of crew members; ensuring planetary quarantine; analysis of emergency situations and development of recommendations for promising MSOs; images of a lunar space station, manned lunar base, Mars space station, and Mars base; medical and technical requirements for MSO modules; and problems of navigation and automatic and manual control of flight of interplanetary complexes [36, 37].

In the coming years (2015–2020), the research in space biology and medicine will be planned, most likely, according to the state of work on further development and operation of the ISS [26, 28, 29, 49]. The main tasks of crews in the framework of international cooperation will include the improvement of the medical safety assurance system, including studies on reducing the expected projected health risks, and the implementation of basic research and experiments in the field of gravitational biology and physiology.

Modern medical support of flights to the ISS is characterized by an increased volume of work on medical support of crew members, with allowance for a

doubling of the number of launches of manned and cargo vehicles and an increase in the number of crew members of the main missions up to six persons, as well as by the complexity of tasks of planning, coordination, and implementation of flight and medical operations, including those occurring in emergency situations associated with a possible refusal of medical and exercise equipment [28, 29, 41, 43]. It is known that, starting from June 2009, medical care is provided on the basis of the principles of separate responsibilities of the partners to maintain the health of the crews of the Russian and American segments and the use of onboard resources (trainers, life support systems, nutrition, and medical care), taking into account the mutual balance of contributions under the ISS program. In this regard, it is necessary to perform further research to reduce the projected health risks of current and future manned missions.

The prospective space missions suggest the solution to a difficult complex of problems, mainly at the intersection of different fields of science. With regard to space biology and medicine, further discussion of the prospects of long-term flights is most relevant in light of the “humanization” of new projects—efficiency, level of functional reserves, reserves of mental adaptation, psychophysiological reliability of activity, and the psychological problems of joint work with crew members from a different cultural, national, religious, and professional background. These and other problems can become limiting factors in flights of varying duration.

Long-range prospects for the development of manned vehicles are associated with the study and development of deep space, and Mars in particular [49]. It is worthwhile to consider ground-based model studies and complex experiments related to solving the medical problems of a manned mission to Mars in light of these prospects. This category includes the 520-day, ground-based comprehensive experiment with confinement and tests of the components of the medical support of the crew of the Mars mission, which is currently being performed at the Institute of Biomedical Problems, Russian Academy of Sciences. In this experiment, the technologies of biological life support systems and the control parameters of the environment are being developed, the impact of physical and chemical factors on the main physiological systems of the body in confinement are being assessed, and the dynamics and patterns of human–biological life support systems interaction are being studied. A large body of the research in the 520-day experiment is devoted to the solution of psychophysiological problems (in particular, the development of advanced tools and methods for the control of operators and their psychophysiological state, optimization of the system of selecting and training of crew members, and providing the intragroup interaction between the crew members with allowance for the individual characteristics of participants).

The possibility of manned flights to other planets is a powerful stimulus for the further development of science and technology, including space medicine and biology. Creating space systems for missions to the Moon and Mars will require the development of innovative biomedical technologies that will provide, first of all, for the reliability and safety of the mission crews. Naturally, when addressing the biomedical problems of manned missions to the Moon and Mars, the experience gained in providing long-term near-Earth flights and the flights of American astronauts to the moon will be used. Studies of the effect of long-term exposure to microgravity on the body and the problems of artificial gravity as a means of maintaining the optimal functional state of the human body in interplanetary flights will be continued. The bases for these studies should be the ISS and automated spacecrafts Bion-M, Foton-M, and Back-ICA.

Directions of Anticipating Work in Space Biology and Medicine

Analysis of published data makes it possible to speak about many features and nuances of the interpretation of the term “anticipating” in relation to the realities of Russian fundamental science. For space biology and medicine, the most important meanings of the word “anticipating” are as follows:

- The use of the best national schools and research directions in the interests of such sectors of space biology and medicine as the physiology of functional systems, gravitational and cell biology, biotechnology, and ionizing and nonionizing radiation biology.

- The development of the most integrated fields of medical and biological sciences, focused on solving the major scientific, technical, and technological problems, such as biomedical provision and the safety of SFs; sophisticated systems for human life supply in extreme conditions; extreme physiology; the physiological–hygienic and epidemiological problems of long-term human confinement; the physiology and medicine of healthy subjects and those of dangerous professions; the psychology and psychophysiology of small groups; engineering psychology; ergonomics, etc..

- The introduction in the practice of ground-based and flight studies of new biomedical technologies and related areas of medicine, primarily molecular biology, medicine, genetics, immunocytochemistry, medical robotics, medical informatics and telemetry, and nanotechnology.

- Close cooperation with breakthrough projects in other areas of basic research of the Russian Academy of Sciences, especially with those in materials science, nanotechnology, microelectronics, renewable energy sources, etc.

- The creation and development of a unified information database of various scientific and practical institutions, to a certain extent involved in con-

ducting biomedical research and experiments in space.

Analysis of trends in the development of space technologies and political assessment of the possible technical and health risks, with allowance for the interests of national security and prospects for the development of space biology and medicine [39, 40], suggests the need to enhance the degree of interpenetration of scientific ideas in Russia and CIS and non-CIS countries for the development of technologies in which there may be a delay in expected scientific advances and their implementation in practice; to forestall losses of human resources and technologies in case they are impossible to recruit abroad; to search for ways to raise scientific projects to the All-Russia level and to diversify education, creating training programs on conducting research and experiments in space and introducing them into the education of schoolchildren and students.

Integration of space biology and medicine with other fields of basic research should also be considered as a relevant direction of “anticipatory” activity. Proceeding from the Plan for Basic Research of the Russian Academy of Sciences for the period up to 2025 and from a number of other documents [33, 38, 39], the following interdisciplinary areas of work can be identified:

- Study of the effect of physical fields of natural and artificial origin on biological systems and humans during implementation of interplanetary missions, with application of different technologies for the protection and prevention of disorders; the study of the mechanisms of human adaptation to various industrial (technogenic) conditions, including the elucidation of the molecular, structural, and functional bases of individual sensitivity and stability of humans and animals to physical, chemical, and biological environmental effects, with the development of tests for a rapid diagnosis; distinguishing local and integral “markers” of the ability of the body to adapt, which will allow for individual selection of subjects for work in the most demanding space missions.

- Development of methods of physicochemical and molecular biology, as well as genetic and cell engineering, to meet the challenges of long-term prediction of possible health disorders in crew members during interplanetary missions, including new methods for genetic diagnosis of the risk of cardiovascular diseases.

- Creation of new biotechnological and bioengineering systems to ensure environmental safety in confinement, as well as the development of methods and means of maintaining a stable ecological balance during the stay of humans in confinement.

- Creation of new generations of life-support and protection systems for the crews of MSOs in emergency situations; the development of methods and means of medical and technical support of crews who

suffered as a result of accidents on board the MSO; an increase in the arsenal of personal protective equipment and rescue, including the elements of “smart clothes,” micro-miniature tools for monitoring the vital functions in extreme environments; creation of the means of visualization of the human condition during implementation of dangerous operations, etc.

—Ensuring environmental safety in confinement objects that are components of multi-element MSOs; development of methods and means of rapid toxicological-hygienic control of the environment; prediction and mitigation of accidents in confinement; development of methods of manual and automatic (with the use of robotic systems) implementation of “domestic” operations for processing wastes and the disposal of harmful contaminants in air, water, and on surfaces of work areas in confinement; optimization of energy consumption during professional activities with allowance of the stay of cosmonauts in specific work areas and of work with a specific type of equipment and payloads.

—Creation of new medical robotic systems making it possible to provide a graded load on different muscle groups, contributing not only to the recovery of disturbed motor function but also to the return to a particular operator of the inherent movement patterns based on the expertise of the individual characteristics of motor functions and gaining the necessary physical shape.

—Development of scientifically substantiated principles of designing robotic systems (exoskeleton technology) for extravehicular activity and long-term maintenance of physical activity of operators at extremely high physical loads on the basis of biomechanical modeling of “man—protective robotic design” complex systems driven by biofeedback principles.

As for future long-term manned SFs, of particular interest is the use of the latest methods of physicochemical and molecular biology, as well as genetic and cell engineering, to perform the following research and development to meet the challenges of the protecting the body from various types of damaging effects of physical factors and validation of new means and methods for the prevention of their adverse biological effects:

—Study of the mechanisms underlying the decrease in the resistance of the body at the tissue and cellular levels under the influence of changed physical factors of the environment, with prediction of the short- and long-term consequences for the health, efficiency, and career longevity of cosmonauts.

—Study of the metabolic processes that determine the immunobiochemical and nutritional status of the body, the molecular mechanisms of regulation of visceral functions, capillary permeability, and angiogenesis mechanisms, molecular physiology of water—salt metabolism, and energy capabilities of humans in per-

forming various types of hard physical and mental work, and the risk of the development of maladaptive disturbances of the regulation of tissue homeostasis for the purposes of diagnosis and medical care.

—Identification of genetic and serological markers of diseases that may develop as a result of chronic occupational exposures and occupational stress, development of the methods for the treatment and prevention of chronic non-infective diseases whose course in long-term flights may differ from that in normal conditions, as evidenced by a significant decrease in the age of the onset of these diseases in groups of subjects with hazardous occupations, which may lead to reduced tolerance to extreme flight factors.

—Development of new methods for the rehabilitation of cosmonauts, with the restoration of altered body functions on the basis of knowledge of their systemic organization, including the levels of possible tissue and intracellular damage caused by the effect of factors of interplanetary SFs.

—Development of ways to control physiological processes in the body of an astronaut in flight in order to increase adaptive capacity and resistance.

—Development on the basis of biochemical and molecular biological research of methods for assessing the toxicity, carcinogenicity, and teratogenicity of newly developed materials and pharmaceutical products intended for use in the complex protection of the cosmonaut's body, in the stimulation of physical and mental efficiency and the correction of stress-induced disorders.

—Study of the detection methods for the physical and chemical structure of substances that can form during the destruction of nanomaterials used in the construction of MSOs, which may potentially deteriorate the functional activity and mental health of cosmonauts, especially in the stages of making responsible decisions related to the safety of work at MSO.

—Biomedical (including toxicological and hygienic) study of low-intensity physical and chemical factors, the threshold of their effect on the functional systems of the human body, and the possible damaging effects at the cellular and tissue levels.

—Study of the effectiveness of using artificial gravity as a means of maintaining optimal functional status of the body in long-term SFs.

—Study of the molecular mechanisms of adaptation and ways to improve the resistance of the human body to adverse factors—cold, hypoxia, physical overloads, hypokinesia, microgravity, space radiation, and modified atmosphere; analysis of the characteristics of regenerative processes in humans with intermittent or long-term exposure to extreme conditions.

—Study of the methods of cell therapy based on cryogenic storage of cell and tissue material on board the MSO and the development of methods to stimulate wound-repair processes in the case of traumatic injuries.

—Study of the mechanical properties of biological tissues at different types of static and dynamic loads and the analysis of the biomechanical characteristics of the musculoskeletal system and the human body and the study of the role of the kinesthetic afferentation in spatial orientation and the provision of stability of sophisticated biomechanical structures at various external perturbations.

At the stages of professional selection of candidates for long-term SFs, it will be necessary, based on the fundamental developments of space biology and medicine (site of the Institute of Biomedical Problems, Russian Academy of Sciences: <http://www.imbp.ru/webpages/win1251/Science/Science.HTML>), to solve the following scientific and practical tasks a new level:

—Immunobiochemical correlations of the development of psychogenic disorders in cosmonauts under conditions of occupational stress and the mechanisms of reduction in resistance to stressful conditions of professional activity.

—Molecular mechanisms of maintaining homeostasis during long-term stay of cosmonauts in artificially modified atmospheres in confinement, including the mechanisms of oxygen transport in the body and changes in the hemodynamic and hemostasis indices under these conditions.

—Mechanisms of thermal regulation of humans under extreme conditions using materials with the heat-accumulating effect based on nanotechnologies and substantiation of requirements for the creation of “smart clothing” with improved physiological-hygienic characteristics.

—Methods for detecting genetic markers for expert examination of candidates to identify the subjects prone to oncological, cardiovascular, and other diseases [2, 3].

—Energy and metabolic characteristics of the body that affect the state of the functional reserves, including the cardiorespiratory system.

The complexity of these tasks requires the integration of studies of different scientific and educational institutions through the implementation of certain activities, such as the strengthening the scientific contacts (under the RD projects, etc.) with institutes of the Russian Academy of Sciences, departmental research centers, and higher education institutions; active use of high-performance computing resources, software and informational support for automated systems, research facilities, and equipment for collective use; and the allocation of targeted funding for basic research in space biology and medicine to the participants of space projects.

SUMMARY

Space programs implemented in Russia today, both independently and in cooperation with other coun-

tries, show that its rightful participation in the development of international cooperation strategy is the result of both scientific and technological anticipation and the advantaged position won in previous periods, especially in the first, “Gagarin” period of manned space flights.

A question arises as to whether Russia will, in the near future, use its historic opportunity to consolidate its position in space and to assert the role of manned space flight as the most integrated and high-tech sector of innovative achievements, or if it or lose its scientific and technological positions. The answer to this question will determine the development of the space industry, not only at the current stage, which is set by the Federal Space Program of Russia for 2006–2015, but also in the longer prospects until 2040, as well as the fate of Russian basic space science, an integral component of which is the space biology and medicine.

CONCLUSIONS

(1) The new space projects will play a particular cumulative and “catalytic” role in the development of basic research and in the plans for the innovative development of Russia, as is evidenced by the national history of rocket and space technology and biomedical technologies for the supply of space flights of humans and other living beings.

(2) One of the “locomotives” of science and technology in Russia can and should be manned space flights. In this area, a powerful squad has formed, consisting of highly qualified experts. They are not only able to continue work on existing developments, but they are also capable of scientific creativity, the performance of challenging test work, the preparation of large-scale laboratory and flight experiments, and the solving of complex problems with the highest demands on safety of personnel and environment. They know the technologies of selection and the ground-based preparation of test persons of dangerous occupations for work in space projects.

(3) In accordance with the objectives set out in the Federal Space Program of Russia for 2006–2015, the basic conceptual approaches to the selection of the directions of development of Russian space exploration, including space biology and medicine, were formed. However, the choice of options to achieve rapid and complete implementation of various space projects is still actively debated. This most significantly affects the strategies of basic and exploratory research. Obviously, they should be planned to ensure not only the preservation of what has already been achieved, but also the creation of favorable conditions for strengthening national priorities and advancing in the most critical areas of science, including its essential and integral part—biomedical research in flights of manned and unmanned spacecraft.

(4) Retaining the priority of space research, including the biomedical studies, is a prerequisite for favorable development of Russian basic research. Ignoring the sciences involving life and the capabilities of the human body can lead to irreversible degradation of the whole field of basic research, as well as the loss of key technologies, without which the risks associated with the safety of future manned spaceflights will become unacceptably high.

(5) Space biology and medicine, with the existing cooperation of its basic research and testing organizations and allowance for the long-term work plans and priority research directions of other institutions of the Russian Academy of Sciences, should be prepared for the most probable scenarios for Russian space activities. A key condition for the ability to meet new challenges is the continuous and purposeful continuation of basic and applied biomedical research on manned and unmanned spacecraft. The starting point of movement should be the clearly and unambiguously formulated priorities in biomedical research in space as a basis for strategic planning for basic research. Maintaining the existing "scientific fabric" and the establishment of the succession of generations of researchers should remain the major component of this planning.

(6) Russian researchers have created certain experimental and theoretical advances in the biomedical support of a long-term manned mission to Mars. In terms of ensuring the crew safety for future "ultralong-term" missions (including interplanetary ones), conducting exploratory research to create an artificial environment that meets the requirements of self-regulation and maintenance of homeostasis in a wide range of disturbing factors and risks under conditions of flight autonomy without receiving extensive help from the Earth is one of the most promising areas for international cooperation in the current and future space development projects.

(7) In the face of fierce competition for resources, funding, and confidence in public and state institutions, only the anticipation of the demands and needs of the high-tech sector of space science and technology and long-range planning of the paths and rates of development of space biology and medicine can ensure the balance of natural requirements, both to a rapid practical realization in SFs of the achievements of biomedical sciences and to the advanced level of studies that meet the high standards of basic science.

(8) The interests of further successful development of Russian space biology and medicine require a continuation of the efforts to create a stronger scientific cooperation with foreign research institutions and space agencies.

REFERENCES

1. Afanas'ev, I.B., The immediate prospects for manned spaceflights, *Novosti Kosmonavt.*, 2009, no. 1, p. 24.
2. Baranov, V.S., Molecular medicine: molecular diagnostics, preventive medicine and genetic therapy, *Mol. Biol.* (Moscow), 2000, vol. 34, no. 4, p. 684.
3. Bogomolov, V.V., Voronkov, Yu.I., and Larina, O.N., Identification of individual parameters of the genotype that are informative for medical support of manned space flights: modern possibilities and prospects, *Aviakosm. Ekol. Med.*, 2006, vol. 40, no. 1, p. 22.
4. Buravkova, L.B., Problems of gravitational biology of the cell, *Aviakosm. Ekol. Med.*, 2008, vol. 42, no. 6, p. 10.
5. Interview with Academician E.M. Galimov, *Nezavis. Gazeta*, 24.03. 2010; *Ross. Gazeta*, 19.03. 2010. <http://www.ras.ru/digest/showdnews.aspx?id=594a595b-4101-4546-aa63-f851281df390&print=1>
6. Gazenko, O.G., The exploration of space is impossible without the man, *Ros. Vesti*, 2006, no. 1–2, p. 18.
7. Gazenko, O.G., On the 40th anniversary of Yuri Gagarin's space flight, *Mavritaniya, Kosm. Al'manakh*, 2001, no. 4, p. 3.
8. Gazenko, O.G., Grigor'ev, A.I., and Egorov, A.D., Space medicine yesterday, today, and tomorrow. The first steps, short-term and long-term flights, in *Nauka v Rossii* (Science in Russia), Moscow, 2006, vol. 3, p. 5.
9. Gazenko, O.G., Grigor'ev, A.I., and Malashenkov, D.K., Space biology and medicine at the threshold of the 21st century. Website of the Institute of Biomedical Problems, Russian Academy of Sciences. http://www.imbp.ru/WebPages/win1251/Articles/2000/KBM-21_r.html
10. Galimov, E.M., *Zamysly i proshchety: Fundamental'nye kosmicheskie issledovaniya v Rossii poslednego dvadtsatiletiya. Dvadsat' let besplodnykh usilii* (Plans and Failures. Fundamental Space Research in Russia in the Last Twenty Years: Twenty Years of Fruitless Efforts), Moscow, 2010.
11. Grigor'ev, A.I. and Il'in, E.A., Animals in Space, *Vest. Ross. Akad. Nauk*, 2007, vol. 77, no. 11, p. 963.
12. Grigor'ev, A.I., The contribution of Academician O.G. Gazenko to the development of the basic problems of space biology and medicine, *Ross. Fiziol. Zh. im. I.M. Sechenova*, 2008, vol. 94, no. 12, p. 1345.
13. Grigor'ev, A.I., Baranov, V.M., Bogomolov, V.V., and Sinyak, Yu.E., Medical and technological aspects of designing life-support systems for deep space exploration, *Aviakosm. Ekol. Med.*, 2008, vol. 42, no. 6/1, p. 5.
14. Grigor'ev, A.I. and Pestov, I.D., Patriarch of space biology and medicine: in memory of O.G. Gazenko, *Nov. Kosmonavt.*, 2008, no. 1, p. 70.
15. Grigor'ev, A.I. and Potapov, A.N., Achievements and prospects of space biology and medicine, in *50 let kosmicheskikh issledovaniy* (50 Years of Space Research), Moscow, 2009, p. 198.
16. Il'in, E.A., The Bion Program: from the past to the future, *Aviakosm. Ekol. Med.*, 2008, vol. 42, no. 6, p. 45.
17. Innovative activities of the Russian Academy of Sciences. Russian Academy of Sciences. Site of Russian Academy of Sciences. <http://www.ras.ru/scientificactivity1.aspx?print=1>
18. Internet briefings of the Federal Space Agency, Press service of Roskosmos. Interview. Aleksei Krasnov, head of manned space program management. State Secre-

- tary, Deputy Head of Roskosmos V.A. Davydov. <http://www.federspace.ru/>
19. Kozerenko, O.P. and Ponomareva, I.P., Psychophysiological aspects of manned space flight supply, *Aviakosm. Ekol. Med.*, 2008, vol. 42, no. 6, p. 84.
  20. Kozlovskaya, I.B., Pestov, I.D., and Egorov, A.D., The system of prevention in long-term space missions, *Aviakosm. Ekol. Med.*, 2008, vol. 42, no. 6, p. 66.
  21. Kopik, A.G., Interplanetary stations. Russian projects of Martian machines, *Nov. Kosmonavt., Vypuski*, 2005, no. 10, p. 52.
  22. Koroteev, A.S., Nuclear power can provide a quantum leap in the development of space. Roskosmos Press Service. <http://www.federspace.ru/main.php?id=182>
  23. Space Biology, in *Bol'shaya sovetskaya entsiklopediya* (The Great Soviet Encyclopedia).
  24. Space medicine. From Wikipedia—The Free Encyclopedia. http://ru.wikipedia.org/wiki/space_medicine
  25. *Kosmonavtika XXI veka. Popytka prognoza razvitiya do 2101 goda* (Space XXI century: An Attempt to Forecast the Development up to 2101), Chertok, B.E., Ed., Moscow, 2010.
  26. A brief history of space research in Russia. Roskosmos Press Service. <http://www.federspace.ru/main.php?id=55>
  27. Round table "Man in Space: Is there a border?," News of RAS, 21.05. 2010, 27.05.2010. <http://www.ras.ru/news/shownews.aspx?id=7782061c-6886-4787-a083-8db26d43af92>; <http://www.ras.ru/news/shownews.aspx?id=53c1e662-7935-43c1-80f4-033a244db0bf#content>
  28. Lopota, V.A., Horizons of manned space flight projects (based on the report at the 32th Royal readings), *Polet. Obscheros. Nauchn.-Tekhn. Zh.*, 2008, no. 5, p. 10–17. Official site of RSC "Energia" Korolev. http://www.energiya.ru/rus/news/news-2008/public_05.html
  29. Lopota, V.A., Russian manned space flights: a new look at the prospects, *Polet. Obscheros. Nauchn.-Tekhn. Zh.*, 2009, no. 7, p. 3.
  30. Lopota, V.A. and Zaborovskii, V.S., The prospects for a global information society: priorities and objectives of development of Russian high technology, Regional Network for Education and Science RUSnet. <http://www.neva.ru/conf/art/art6.html>
  31. Proceedings of the International Workshop "The Use of Dormancy in Space Exploration," June 12–13, 2009. Zoological institute, Russian Academy of Sciences, St. Petersburg, Russia. http://www.zin.ru/conferences/Space_Dormancy/index.html
  32. International and national programs in the United States. On the Reform of the Space Policy, *Raketa. Kosmich. Tekhn.*, 2010, vol. 30, no. 2642, p. 1.
  33. Methodological basis of forecasting of scientific and technological development of Russia until 2030, using the criteria of strategic risks. <http://www.ras.ru/scientificactivity/scienceresults/prognosis.aspx>; <http://www.ras.ru/FStorage/Download.aspx?id=4e42ec47-32bb-44ba-a6e8-7f2cd63de687>; <http://www.ras.ru/FStorage/Download.aspx?id=5f47fe85-3594-4b3a-84b9-e63b640eaec4>
  34. The basic problems of space (from the report of Academician Boris Evseevich Chertok, an ally of Sergei Korolev, at the 6th International Aerospace Congress IAC'09), Press Service of the Russian Federal Space Agency, 26.08.2009. <http://www.federspace.ru/main.php?id=4&nid=197>
  35. "The List of Critical Technologies of the Russian Federation" approved May 21, 2006, Pr-842.
  36. Perminov, A.N., Six persons from the ISS, *Ross. Gaz., Fed. Vyp.*, 2010, no. 5155 (76). April 12. <http://www.rg.ru/2010/04/12/kosmos.html>; <http://www.rg.ru/2010/04/12/kosmos.html>
  37. *Pilotiruemaya ekspeditsiya na Mars* (Manned Mission to Mars), Koroteev, A.S., Ed., Moscow, 2006.
  38. Plan for Basic Research of the Russian Academy of Sciences for the period up to 2025. Site of Russian Academy of Sciences: <http://www.ras.ru/scientificactivity/plan2025.aspx>
  39. Resolution of the Presidium of the Russian Academy of Sciences no. 211 from 08.09.2009 "On the Formation of Councils to Coordinate Scientific Research on the Priority Directions of Technological Breakthrough of the Presidium of the Russian Academy of Sciences. <http://www.ras.ru/presidium/documents/directions.aspx?ID=fbe08787-871d-4455-b434-d3b187fa4557>; <http://mipt.ru/nauka/akty/prezid-ras.html?xsl:print=1>; <http://www.ras.ru/presidium/documents/directions.aspx?ID=fbe08787-871d-4455-b434-d3b187fa4557>; <http://mipt.ru/nauka/akty/prezid-ras.html?xsl:print=1>
  40. RAS Program "Fundamental Science for Medicine," <http://ras.imbp.ru/index.php?id=3>; http://ras.imbp.ru/file/p_description_2009_11.doc
  41. Raikunov, G.G., One of our goals is the creation of a national space station, *Nov. Kosmonavt.*, vol. 19, no. 8 (319). Inform. period June 1–30, 2009. <http://www.novosti-kosmonavtiki.ru/content/numbers/319/20.shtml>
  42. Order of the Federal Space Agency from January 29, 2010, no. AP-16, "On Informational Provision of Preparation and Celebration of the 50th Anniversary of Yuri Gagarin's Space Flight," Roskosmos Press Service. <http://www.federspace.ru/main.php?id=170>; <http://www.federspace.ru/main.php?id=170>
  43. Russian Space: The Present and the Future: Federal Space Agency Report delivered by V.A. Davydov, Secretary of State, Roskosmos Deputy Head, at the plenary session of the 6th International Aerospace Congress IAC'09, Press Service of the Russian Federal Space Agency, 25.08.2009. www.federspace.ru/main.php?id=4&nid=198
  44. State leaders about Space Exploration. Roskosmos website <http://www.federspace.ru/main.php?id=33>
  45. The National Security Strategy of the Russian Federation until 2020. Approved by Decree of the President of the Russian Federation dated May 12, 2009, no. 537. <http://www.scrf.gov.ru/documents/99.html>
  46. Sychev, V.N., Levinskikh, M.A., Gur'eva, T.S., and Podol'skii, I.G., Biological life support system for space crews: some results and prospects, *Aviakosm. Ekol. Med.*, 2008, vol. 42, no. 6, p. 92.
  47. Tairbekov, M.G., Studies in cell biology in flights of unmanned spacecraft (characteristics of preparation and conduction of experiments), *Aviakosm. Ekol. Med.*, 2006, vol. 40, no. 5, p. 3.
  48. Ushakov, I.B., Bednenko, B.C., Stupakov, G.P., et al., The main stages of development of national space medicine, *Istoriya otechestvennoi kosmicheskoi meditsiny* (History of Soviet Space Medicine), Ushakov, I.B.,

- Bednenko, V.S., and Lapaev, E.V., Eds., Moscow, 2001, Chapter 1, p. 6.
49. The Federal Space Program of Russia for the period 2006–2015 (Russian PCF for 2006–2015). Approved by the Order of the Government of the Russian Federation on October 22, 2005, no. 635. Press Service of Russian Federal Space Agency. <http://www.federspace.ru/main.php?id=24>; http://www.programs-gov.ru/29_1.php
50. Basic Space Research (Roskosmos). Research in space biology, physiology, and material sciences, Web site Roskosmos. <http://www.federspace.ru/main.php?id=25>
51. Hubble (telescope). Works of Repair. Wikipedia—The Free Encyclopedia.
52. Shafirkin, A.V., Kolomenskii, A.V., and Petrov, V.M., Problems of radiation safety in the missions to Mars, *Aviakosm. Ekol. Med.*, 2007, vol. 41, no. 4, p. 39.

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