Anatoliy Ivanovich Grigor’ev is an outstanding scientist who has made a notable contribution to solving the fundamental and applied problems of space physiology and medicine. He is the force behind the new scientific discipline known as gravitational physiology. He has helped shed light on a number of important principles of the functioning of the vestibular, cardiovascular, and endocrine systems, water and electrolytes, as well as mineral metabolism under altered gravity conditions. Grigor’ev’s experimental research and theoretical studies are widely used in the search for solutions to the problems of protecting astronauts’ health during long flights. A system for the medical support of crews during year-long or longer flights has been proven, developed, and implemented under his supervision. The research done by A.I. Grigor’ev, his numerous scientific works, active practical efforts to support manned spaceflight, and participation in international cooperation have earned him a well-deserved recognition both in Russia and abroad.

The first orbital space flights (SF) presented the tasks of studying the effect of space flight factors on the human body, identifying the main patterns of human body adaptation to space environment, and using these findings to develop and implement a scientifically grounded medical health care system for astronauts.

The problem of medical support is multifaceted and includes several interrelated directions. Academician Anatoliy Ivanovich Grigor’ev talks about these problems in his interview with a correspondent of Acta Naturae.

Acta Naturae (AN) correspondent: What scientific studies focus on the justification of the system of medical support of astronauts’ health in your opinion?

A.I. Grigor’ev: Throughout manned space flights, the creation and modernization of the medical health care system for astronauts have been based on the results of fundamental research in space physiology, biology, biochemistry, biophysics, and other scientific disciplines, carried out in ground-based simulation experiments, at biological satellites, and in space missions. This has made it possible to better understand the effect of space flight factors on different functional structures of the body, to explore the patterns of body adaptation in response to their action, and to provide a rationale for approaches to developing a health support system for astronauts during long missions.

In the early years of space exploration, the short-term manned missions were carried out using the Vostok, Voskhod and Soyuz spacecrafts with a relatively “simple” medical support and health control system.

Today, manned astronautics is tasked with the problem of increasing flight duration and the number of crew members. This has required the development of a reliable medical support system for expeditions lasting for several months. The experimental ground-based models simulating the effects of zero gravity were developed at the Institute of Biomedical Problems (IBMP) to solve this problem. They were clinostatic and antiorthostatic hypokinesia (bed rest) and “dry immersion” (immersion of a test subject into a special water bath).

Numerous experiments on clinostatic hypokinesia lasting 15 to 120 days were carried out in 1966–1976. These experiments examined the status of various systems of the body under these conditions in combination with the use of preventive measures (exercises and the use of pharmacological agents). A series of experiments with clinostatic hypokinesia lasting 3–120 days were carried out at IBMP in the 1980s to study the cardiovascular system, metabolism, and features of their regulation. This has made it possible to develop and test a scheme for applying water plus electrolyte additives in combination with negative pressure on the lower part of the body (NPLB), which have be-
come an integral component of the prevention system at the final stage of long SFs.

**AN correspondent**: Which study can be distinguished among the overall series of projects carried out during previous years?

**A.I. Grigor’ev**: The unprecedented for its duration, 370-day-long experiment, with antiorthostatic hypokinesia was carried out in 1988. This experiment studied the dynamics of changes in major body systems, including water-electrolyte and mineral metabolism. The experiment showed that it is possible to use alternative technologies of prevention, which allow one to purposefully enhance the physiological capabilities of an astronaut’s body; in particular to improve the tolerance to g-loads during disorbiting. In a continuous 56-day-long experiment with “dry” immersion, we thoroughly studied the state of the cardiovascular system, water-electrolyte metabolism, and renal function and tested the preventive measures, including exercises and artificial gravity generated by a small-radius centrifuge.

**AN correspondent**: Anatoliy Ivanovich, you are the originator of the new branch of science known as gravitational physiology. Could you please tell us about the main achievements in the field?

**A.I. Grigor’ev**: Gravitational physiology studies the principles of regulation of bodily functions under altered gravity conditions. Important scientific data were obtained in studies conducted at 11 biological satellites, which were carried out with the participation of experts from Russian and foreign scientific centers (coordinated by E.A. Il’in). The research was conducted in many biomedical disciplines using a broad evolutionary range of biological objects (from microorganisms to primates). These studies, in cooperation with Yu.V. Natochin, have provided important data for understanding the mechanisms of metabolism adaptation in living organisms exposed to altered gravity. These results significantly contribute to the theory of space biology.

The following general theoretical achievements are considered to be important ones: the discovery of changes in the sensitivity of end organs to biologically active substances in humans during long SFs; defining the role of shifts in water-electrolyte metabolism in the development of vestibular disorders, orthostatic instability and reduced tolerability to accelerations; identification of the mechanisms of restructuring water and ion transportation systems in the kidney; and establishing ways to minimize physiological functions under these conditions. We have implemented programs studying the cardiovascular system and metabolism during long flights and uncovered previously unknown mechanisms of endocrine regulation of metabolism in zero gravity. When studying the effects of microgravity on human multipotent stromal cells (MSCs), in cooperation with L.B. Buravkova, structural and molecular-genetic changes in the MSCs of human bone marrow were detected. These results are indicative of the presence of gravity-dependent intracellular mechanisms that lead to both early and late responses of progenitor cells to the simulation of the effects of microgravity, thus indicating the specific role of the actin cytoskeleton, being the basic cell structure (including stem cells), as a gravitationally sensitive cell structure. Studies focused on the molecular mechanisms of the changes detected in MSCs under these conditions have shown transient changes in the level of expression of the structural and regulatory genes associated with the actin cytoskeleton. It has been established for the first time that this effect significantly changes the expression pattern of the genes, being “stem cell markers,” including the genes encoding the proteins involved in intracellular signaling, cell adhesion, and the regulation of proliferation and differentiation of stem cells.

The simulation experiments and flight studies performed allowed us to justify, and later to develop and put into flight practice, methods for the medical control, prediction and management of the human status, to create a complex of technologies to mitigate the adverse effects of zero gravity, and this contributed to the launching of long-term missions at the Mir orbital station (OS) and allowed our country to assume a leading position in manned astronautics.

**AN correspondent**: In 1996–2008, you were the head of the medical support service of the missions at the Mir orbital stations and International Space Station (ISS). Could you please tell us more about that?

**A.I. Grigor’ev**: Our team has developed a system for rendering medical support to crews during long-term orbital flights, which includes the following components:

- medical selection, periodic and preflight medical examination of astronauts, medical certification;
- biomedical crew training;
- maintaining the health and performance of astronauts during an orbital flight: health monitoring, medical diagnosis, a system of preventive measures, functional state management, psychological support, medical assistance (if necessary), radiation monitoring and environment control;
- post-flight medical rehabilitation to restore the health of space crews;
- healthcare support for the development of manned spacecraft; and
- medical and technical support for the development of satellite-borne biomedical support measures.

**AN Correspondent**: Anatoliy Ivanovich, we know that you were the chairman of the Chief Medical Commission of the Russian Space Agency for the certification of as-
ticians and candidates for astronauts and candidates for astronauts from 1990–2008. Could you please tell us about the medical selection and training of astronauts?

A.I. Grigor’ev: The system of medical selection of astronauts developed in cooperation with the experts of the Yu.A. Gagarin Cosmonaut Training Center includes a comprehensive medical examination of astronauts to assess their physical and mental health, to determine the functional capacities of the body according to results related to tolerance to special stress tests. The latest advances in medical science and technologies are being used when upgrading the selection system. The parameters of the astronauts’ genotype are studied, along with extensive physiological and biochemical research, in order to predict tolerance to extreme conditions. Increasingly more attention will apparently be focused on the “genetic predisposition” of a person to tolerance to g-force associated with the pre-training and directly with long-term stays in space.

AN correspondent: How is the medical control of a crew’s health conducted during flights?

A.I. Grigor’ev: The medical control during SFs is based on integrated monitoring aimed at assessing the current state of astronauts’ health, dynamic monitoring of the basic functions of their bodies and the habitat, and controlling regulation and adaptation to the living environment. The structure of the medical monitoring allows us to identify the adverse conditions that may develop during flight and, if necessary, to conduct emergency surveys according to predictions. The system for minimizing health risks in case of potential failures of the life support system and technical problems during flight operations was developed and functions effectively now. Modes, measures and methods of prevention have also been developed, tested in ground-based experiments, and implemented in flights. The system of preventive measures has been developed and successfully implemented at all stages of long-term missions in collaboration with O.G. Gazenko, A.S. Barer, L.I. Kakurin, I.B. Kozlovskiy, I.D. Pestov, B.V. Morukov and other IBMP staff. The onboard prevention system includes physical exercises using atreadmill, cycle ergometer, and press machines, muscle loading along the longitudinal axis of the body using the Penguin suit, low-frequency electrical stimulation of the muscles, the effect of negative pressure on the lower part of the body using the Chibis pneumatic-vacuum suit, drugs and other measures to prevent potential disorders of the functional state during a space flight. The important purposes of the system at the initial phase of the flight include prevention and relief of manifestations of the adaptation syndrome, while the purposes of the final stage include measures to prevent post-flight orthostatic instability (NPLB and water plus electrolytes additives).

The studies conducted during and after SFs have shown that the Russian preventive system is effective in preventing or reducing the adverse effects of exposure to zero gravity and other adverse factors of long-term SFs. It has become the basis for the medical support of crews at the International Space Station.

AN correspondent: Could you please describe the structure of the health care system?

A.I. Grigor’ev: The onboard health care system is based on the principle of nosology. It was developed on the basis of the most recent achievements in clinical medicine, taking into account the specific conditions of space flights. The Russian system of medical aid includes an onboard medical kit and a set of specialized medical packages for emergency care, packages with cardiovascular agents, gastrointestinal agents, antiseptic and other drugs. In some cases the medical care kit at the Mir and ISS orbital stations has made it possible to conduct curative measures in acute and emergency conditions and injuries, which have made it possible to diagnose and monitor the targeted treatment. The studies carried out in cooperation with I.P. Neumyvakin, L.L. Stazhadze, V.V. Bogomolov, I.B. Goncharov, A.D. Egorov and the staff of a number of clinics in Moscow and St. Petersburg have significantly contributed to the formation of the health care system at orbital stations.

AN correspondent: Anatoliy Ivanovich, what about the implementation of new remote-action technologies in the medical monitoring of astronauts?

A.I. Grigor’ev: Space telemedicine has been in constant improvement and implemented since the 1990s. This has allowed us to significantly improve medical care during SFs and at landing sites. The practical use of telemedicine in SFs significantly complements the capabilities of diagnosis and analysis of the effectiveness of health care.

AN correspondent: And how do you control the environment and radiation?

A.I. Grigor’ev: Much attention is given to the monitoring of the OS habitat, including the assessment of air quality and monitoring of the concentrations of toxic substances. A classification of pollution levels has been developed, and personal protective equipment has been designed. Assessment of onboard water quality and the level of microbial contamination are regularly conducted during flights. The level of noise in the living compartments of OSSs is regularly assessed and otoprotection methods are being elaborated when it is exceeded. Scientific and methodological materials related to the radiation safety of orbital station crews have been developed, and a permanent Radiation Safety Service for Space Flights has been
formed. It is equipped with facilities for continuous monitoring of the radiation environment along the flight path and in the living compartments, including the assessment of radiation doses and radiation risk to crew members, development and implementation of recommendations for minimizing the radiation hazard to the crew. With the prospect of interplanetary missions, we have been paying a great deal of attention to research into the effect of heavy ions on living systems.

**AN correspondent:** Is post-flight medical rehabilitation equally topical at present?

**A.I. Grigor’ev:** IBMP staff have thoroughly analyzed the changes in the state of many systems of the body of astronauts which occur after long-term flights and require special health rehabilitation measures for their recovery during the post-flight period. They have improved some measures and methods of post-flight rehabilitation; designed a medical-evacuation complex and medical equipment for examination and medical assistance to astronauts at the landing site; and developed methods of medical care after a flight. These studies were further developed in connection with flights to the ISS. IBMP staff (B.M. Fedorov, T.D. Vasil’eva, V.V. Bogomolov) and Yu.A. Gagarin CTC staff (V.V. Morgun, V.I. Pochuev, O.V. Kotov) have conducted a series of studies aimed at developing a set of methods and measures for restoring astronauts’ health after long-term flights which uses individual schemes and regimens of interventions during rehabilitation.

The main result of the medical support system that we have developed for the crews flying to the Mir and ISS O5s is the maintenance of health and the ability of crew members to perform, which are sufficient for effective implementation of flight programs, as well as a favorable course of rehabilitation given adequate restorative and therapeutic measures. It is important to mention the active role of astronauts, especially physician astronauts, in the implementation of this system. The effectiveness of the Russian system of medical selection, medical monitoring of the health of crews during long-term flights, and the system of onboard prevention and post-flight rehabilitation has been proved. This was also demonstrated by the successful extra-long-term missions, including the uniquely complex flights of V.V. Polyakov (a 438-day flight) and S.K. Krikalev (803 days in 6 flights).

**AN correspondent:** Anatoliy Ivanovich, what is the ground that space medicine has covered from orbital stations to interplanetary flights?

**A.I. Grigor’ev:** The achievements in the creation and successful use of the Russian medical health care system for astronauts during long-term space missions underlie the development of the concept of biomedical support during interplanetary missions. The research and developments in this field are being conducted at IBMP. The international 520-day-long interplanetary flight modeling experiment (Mars-500 project) that was carried out in 2010–2011 was the most significant one. The system of medical support for crews’ health was worked out during this experiment, the technological operations of “landing” on Mars have been modeled, and important data on the dynamics of the status of the main body systems during prolonged isolation have been obtained. The experiment has been praised by the international scientific community.

**AN correspondent:** Can the achievements of space medicine be used in clinical practice?

**A.I. Grigor’ev:** We actively suggest using our achievements in public health care practice. In collaboration with clinicians at some medical institutions we have managed numerous unique achievements during SFs and in simulations of vital functions of the body under ground-based conditions in the Russian health care system. In particular, we have designed a number of measures for preventing and correcting motor disorders (special loading suits, neuromuscular stimulation facilities, etc.) in cooperation with I.B. Kozlovskiy and E.P. Tikhomirov. During tests, these facilities were adapted to the needs of the clinic for children with cerebral palsy (K.A. Semenova) and persons who have suffered traumatic brain injury and strokes (A.B. Geht, L.A. Chernikova, V.M. Shklovskiy et al.). Now these facilities are successfully “running” at the manufacturing venture at IBMP (I.V. Saenko).

New experimental data for the analysis of the destructive and adaptive processes taking place in human bone structures and changes in the mineral metabolism under conditions of reduced gravity load were obtained, and a system for the correction of musculoskeletal system disorders in zero gravity and hypokinesia has been developed in cooperation with V.S. Oganov.

**AN correspondent:** Anatoliy Ivanovich, let me congratulate you on the important government award and thank you for this interview. We would like to wish you success in the area of knowledge, where our country has been at the forefront for many years, and, judging from what you have told us, is not giving up its position today.

**A.I. Grigor’ev:** Thank you for your congratulations. I would like to mention that this research is work made by a large team, including not only IBMP staff, but also all staff at institutes and industrial organizations — our “cooperation” that I was lucky to head for many years. I would like to thank all my colleagues and congratulate them on our shared success!