

**The Russian-U.S. Experience with Developing Joint Medical Support Procedures
for Before and After Long-Duration Space Flights**

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ABSTRACT

As the Russian Space Agency (RSA) and the U.S. National Aviation and Space Administration (NASA) began in the mid 1990s to plan a preliminary cooperative flight program in anticipation of the International Space Station, programmatic and philosophical differences became apparent in the technical and medical approaches of the two agencies. This paper briefly describes some of these differences and the process by which the two sides resolved differences in their approaches to the medical selection and certification of Shuttle-Mir crew members. These negotiations formed the basis for developing policies on other aspects of the medical support function for international missions, including crew training, preflight and postflight data collection, and rehabilitation protocols. The experience gained through this cooperative effort has been invaluable for developing medical care capabilities for the International Space Station.

Genesis of the Shuttle-Mir Program

In 1992, in response to a formal agreement between the Russian Federation and the United States of America to promote the joint exploration of space for peaceful purposes, the Russian Space Agency (RSA) and the U.S. National Aviation and Space Administration (NASA) began developing a plan for the cooperative exploration of space, a plan that later came to be known as the Shuttle-Mir Program. At the time of the formal agreement, both Russia and the United States had been planning to build new orbital space stations (Mir-2 and Freedom, respectively). In early 1993, plans for Freedom, which involved Canada, Japan, and the European Space Agency (ESA) as well as the U.S., were substantially revised, primarily to reduce expenditures and shorten the project-implementation period. Later that year, Russia abandoned its plans to build a second-generation Mir station and joined the international partnership that was planning the international space station, which by then had been renamed "Alpha."

On 16 December 1993, RSA General Director Yu. Koptev and NASA Administrator Daniel Goldin signed an agreement to establish a preliminary cooperative program between NASA and the RSA as a first step in the joint development of the International Space Station (ISS). This preliminary program, calling for the use of the Russian space station Mir and the U.S. Space Shuttle, was subsequently named the NASA-Mir Program. The program called for 4 or more flights of U.S. astronauts aboard the Mir station, with the total time spent on orbit to be approximately 24 months; up to 10 Space Shuttle missions that involved docking with the Mir

station; and a special program of scientific and technological investigations involving the Russian Priroda and Spektr modules, which were to be equipped with U.S. instrumentation systems for experiments in biotechnology, materials science, biomedical sciences, Earth observations, and other disciplines.

The NASA-Mir program is itself the first of three preparatory phases for the ISS. Phase 1 comprises the joint flights of Russian cosmonauts and American astronauts on the Space Shuttle and Mir station; Phase 2 involves the beginning of construction of the new space station, which will be based initially on Russian and U.S. hardware; and Phase 3 marks completion of construction and habitation of the new station.

Thus, the original Shuttle-Mir program has become a component of the larger NASA-Mir program. The first step in the Shuttle-Mir program ("Shuttle-Mir Phase 1A" in NASA parlance) was to involve the flight of Russian cosmonauts on the U.S. Space Shuttle. The second step ("Shuttle-Mir Phase 1B") was to fly U.S. astronauts aboard the Russian orbital station Mir. The third step in the Shuttle-Mir program was to involve rendezvous and docking between the Space Shuttle and Mir. When this article was written, the Russian cosmonauts S. Krikalev and V. Titov had completed two flights on the U.S. Space Shuttle, the second of which involved a rendezvous at a distance of 11 meters with the Mir station; and the first U.S. astronaut, Norman Thagard, had completed a long-duration flight aboard Mir.

As planning began for the activities to be implemented through the Shuttle-Mir program, programmatic differences in technical and medical approaches became apparent between the two agencies. The sections below describe the process by which the two sides resolved differences in their approaches to the medical selection and certification of Shuttle-Mir crew members.

Identifying Differences in the Approach to Medical Certification

As bilateral discussions began in January 1994 regarding how to select and certify crew members for the STS-60, STS-63, and Mir-18A missions for the Shuttle-Mir program, major differences in approach became apparent in three areas: who is responsible for preflight certification of crew members for missions; features of spacecraft and space technology design; and dealing with the sequelae of long-duration space flight. These topics are discussed in further detail below.

Preflight medical certification for flight. In the U.S. program, medical support for astronauts is provided through the Flight Medicine Clinic at the Johnson Space Center. Crew members undergo annual medical evaluations to maintain their medical certification for flight; they also are tested before and after flight by the flight surgeon assigned to that mission, who is responsible for implementing tests and standards established by NASA and certifying that the crew members are fit for flight. In Russia, two organizations are involved in providing medical support to cosmonauts. On the ground, that support is provided by the Russian State Scientific Research Institute Yu. A. Gagarin Cosmonaut Training Center; in-flight activities are supported by the

Russian Federation State Scientific Center Institute of Biomedical Problems. In Russia, cosmonauts undergo medical testing to qualify for special training, e.g., parabolic flight; centrifuge, vestibular, and barochamber testing; and underwater practice for EVA. Cosmonauts also undergo comprehensive examinations quarterly and before and after flight. They are certified as being medically fit for flight by the Chief Medical Board, which consists of leading medical experts from the Ministry of Defense and of the Ministry of Public Health.

Spacecraft design. The differences in the transport vehicles and spacesuits used by the two agencies have led to substantial differences in the philosophy of how to prepare crew members for flight. The U.S. Space Shuttle is a glider; the G-forces acting on its seated occupants are minimal (up to 3 Gx [chest-to-back] during launch and 1.6–1.8 Gz [head-to-foot] during landing). Thus, the U.S. astronaut-selection process does not include formal standards for the ability to withstand G-force accelerations, and uses fluid loading and anti-G suits to counter the effects of gravity after returning from a microgravity environment. Occupants of the Russian Soyuz transport vehicle, on the other hand, are exposed to 7–9 Gx during nominal descent and 20 Gx or more during emergency ballistic descents. Exposures to accelerations of this magnitude, especially after long exposure to weightlessness, can substantially affect the crew's ability to control the spacecraft and consequently the outcome of the flight. Hence, preparations for Russian flights have traditionally included centrifuge training, which is thought to be required for developing appropriate behavioral reactions and resistance to the effects of acceleration forces. This sort of training is also thought to be informative with regard to revealing hidden subclinical changes in the human body.

Pressure differences between the U.S. and Russian spacecraft have also led to differences in the structure and content of altitude-chamber and extravehicular-activity (EVA) training. Soyuz vehicles are depressurized to an altitude of 4 km (62 kPa) during nominal descent; in the event of emergency depressurization, when cabin pressure reaches that which corresponds to a 5-km altitude (54 kPa), oxygen is fed to the rescue spacesuit. Thus, part of the Russian preflight training includes tests of how well cosmonauts can tolerate moderate hypoxia. In contrast, U.S. astronauts participate in a 1-day training session that involves both lectures and in-chamber demonstrations. The latter involves a simulated exposure to 10.7 km (35,000 ft), a 5-min demonstration of hypoxia symptoms at 7.6 km (25,000 ft), and an explosive decompression. A 2-hour refresher course, including the altitude-chamber demonstration, is required every 3 years thereafter.

Cosmonauts also undergo heat-tolerance training before missions. Failures of the thermal-control system of the Russian EVA spacesuits during operations aboard the Salyut-6, Salyut-7, and Mir stations has led to hyperthermia in at least three cosmonauts. Knowledge of how well a cosmonaut can tolerate thermal loads has enabled Mission Control Center medical group specialists to provide a prognosis for activity in an off-nominal situation. This information also has been used occasionally to temporarily disqualify cosmonauts from training. The U.S. does not use hyperthermia testing to screen or train astronauts.

Moreover, limitations on spacecraft and spacesuit-liner volume dictate that crew members weigh no more than 85 kg (187 lb), have a seated height of no more than 940 mm (37 in), and have a standing height of 1640–1820 mm (64.6–71.6 in). In addition, use of the Sokol-KV-2 rescue space spacesuit and the Orlan-DMA EVA suit require chest circumference measurements of 960–1120 mm (37.8–440.1 in) and 960–1080 mm (37.8–42.5 in), respectively. In the U.S. program, in contrast, space equipment is designed for use by crew members of a much broader size range, namely from the 5th percentile Japanese woman to the 95th percentile U.S. male.

Finally, the Russian program considers the use of provocative vestibular stimuli to be an integral part of the training process, finding such training useful for both predicting and counteracting motion sickness in space. The use of vestibular training is favored over that of antimotion-sickness drugs because of the possible effect of the latter on docking the Soyuz to the station. The U.S. side, by contrast, has not found preflight training to be effective for countering motion sickness in space. Its compromise is to provide antiemetic medications on board and to prohibit scheduling events in which motion sickness would be catastrophic (e.g., EVAs) until the third in-flight day, when most people have adapted to the nauseogenic effects of microgravity exposure.

Long-duration flight. In the Russian program, health requirements for assignment to and certification for long-duration flights are more stringent than those for short flights; moreover, the response to returning to Earth after long flights is thought to require special rehabilitative

measures. At this time, the U.S. has not established formal standards for long-duration crewmembers.

Resolving Differences in Medical Certification for Flight

The emergence of these and other differences between the U.S. and Russian approaches led to much negotiation as to whether to modify the standards used by either side. One example was the debate over whether U.S. standards for preflight certification should be applied to cosmonauts, whether Russian standards should be applied to astronauts, or whether entirely new standards should be developed.

Preflight certification. The preflight certification of Russian crews include some in-depth examinations that are not part of the U.S. certification process. For example, the occurrence of urologic problems during previous Soviet and Russian space flights led Russian specialists to seek possible correlations among changes in blood and urine biochemical indices and the incidence of urologic disorders. No such correlations were found, but the Russian side continues to routinely evaluate urologic function in cosmonauts by internal urography and sonographic evaluation of pelvic organs. The U.S. side, in contrast, analyzes urinary metabolites to evaluate the risk of kidney-stone formation during flight, but does not conduct extensive preflight examinations of the urinary system.

Given the differences among certification procedures between the two agencies, members of the Main Medical Board, the Russian organization responsible for preflight certification, requested additional medical data on the Shuttle-Mir astronauts, and proposed the clinical and functional (i.e., tolerance) tests shown in Table 1. The U.S. representatives agreed to conduct all of the clinical tests except for the contrast urography and GI endoscopy, reasoning that the combination of sonographic evaluation of the kidneys with the standard U.S. evaluation of urinary metabolites and creatinine clearance was sufficiently informative without the additional risk of intravenous dye injection; and that the probability of detecting chronic abnormalities in the gastrointestinal tract in the well-screened astronaut population did not justify the performance of endoscopy.

Negotiations for the functional tests were somewhat more complex. The U.S. side routinely conducts standardized altitude-chamber tests, and proposed that sending the results from these tests to the Russian specialists for review would be sufficient to eliminate the need for further tests of tolerance to hypoxia. As for vestibular training, NASA no longer uses rotating chairs to elicit vestibular responses during training; instead, results from a centrifuge test that the astronauts had undergone were to be sent to the Russian side for review. With regard to physical fitness assessments, astronauts routinely undergo maximum-workload fitness tests on treadmills; NASA proposed that the results of these tests, with the associated electrocardiograms, be submitted instead, and that astronauts participate in an additional cycle ergometry test 30–45 days before the flight. As for the tilt-table tests, the U.S. side emphasized that all of the astronauts assigned or being considered for the Shuttle-Mir program had completed several space

flights and in the process had undergone many tests of their orthostatic tolerance. Results from these previous tests were supplied to the Russian specialists, and the astronauts participated in orthostatic testing 30–45 days before launch. Finally, with regard to acceleration tolerance testing on a centrifuge, the U.S. side agreed that astronauts would complete the preflight training sessions associated with the Soyuz insertion and descent procedures, with the stipulation that the results from those tests were not to be used to determine flight status.

Annual certification. Both agencies require that astronauts or cosmonauts undergo annual medical evaluation to retain their qualification for flight. After discussion of the principles and component tests of that evaluation, both sides agreed that the “sending” side is responsible for performing them. These certifications can be conducted in one of two ways: either the crew member can return to his or her own country to undergo certification, or the “receiving” side provides conditions for certification to be performed by specialists representing the sending side. The U.S. side accepted the Russian medical certification of Krikalev and Titov without additional tests; the additional tests required of U.S. astronauts before they could fly aboard Mir focused on the Russian preflight preparations discussed above.

After the negotiations described above were completed, the participants agreed that a single set of criteria for medical certification, and a single set of on-board countermeasures, should be developed for the ISS program, and this conclusion was presented to the working group charged with implementing the joint Russian-U.S. program (see below).

Defining a Medical Support Function

In April 1994, after negotiations like those described above had been held in several areas, the Shuttle-Mir working group was restructured and its functions clarified. Issues involving ground-based and in-flight medical support became the purview of the "Medical Support Subgroup" (chaired by V. Bogomolov and V. Morgun on the Russian side and by S.L. Pool and R.D. Billica on the U.S. side). This subgroup was charged with supporting the interaction and integration of medical services and structures for joint missions, including developing medical standards for selection and training; evaluating countermeasures; evaluating the effects of the external environment on crew health; providing medical monitoring during flight; rendering medical assistance; providing preventive medicine; and providing rehabilitation. As part of this effort, the U.S. side agreed to assist the Russian side in developing databases of the medical and biological observations made in the course of the Russian space program.

Also at that meeting, the Russian and American sides agreed to form a joint medical council, the "Multilateral Medical Policy Board." The mission of this Board is to define policy with regard to medical support of joint flights, specifically medical evaluation of crew health status (including the development of flight medical kits), medical standards, medical flight rules, countermeasures, normative data from crewed flights, medical support of flights and training, exchange of flight surgeons, and long-term observation. The Board is also responsible for documenting deviations from prescribed procedures, for performing periodic reviews (at least every 6 months) of medical activity, and for initiating work to make corrections as necessary.

Board members are physicians designated by each nation or agency participating in the ISS international partnership. Decisions of the Medical Support Subgroup are subject to the approval of this Board and project management.

The Medical Support Subgroup met in December 1994 to discuss how best to organize the development of joint requirements for the medical support of space flights within the framework of the Shuttle-Mir and NASA-Mir programs. As a first step, it was agreed that these requirements be developed jointly by those NASA and RSA medical structures responsible for maintaining the health and performance of cosmonauts and astronauts. Next, splinter groups were assigned to address issues in the following areas:

- Medical standards for maintaining cosmonaut health (medical selection and monitoring during preflight training and after flight)
- Biomedical training for crews
- Psychological preparation and monitoring before, during, and after flight (with particular attention paid to the work-rest schedule)
- Postflight medical rehabilitation program (for joint crews after long flights on Mir);
- Requirements for medical-support personnel before and after flight (e.g., flight surgeons and emergency medical services)

In terms of legal responsibilities of RSA and NASA structures for the medical support of joint space missions, it was understood that while the Shuttle-Mir program was operational, the

medical support system would be founded on the existing national regulations and the currently accepted medical practice of each country. One exception to this was the obtainment of informed consent to participate from the Russian Mir-18 crew; informed consent is legally required in the U.S. but not in Russia.

Scheduling Training for In-Flight Experiments

Issues regarding scheduling crew training for the conduct of on-board medical experiments were discussed at working group meetings in July and November 1993. The first policy established was that all preflight training was to be completed by 30 days before launch, except for supplemental instruction at the crew's request; baseline data was to be collected during the 30 days before launch.

Also decided at that time was that the Mir-18 crew would arrive in the U.S. 6 months before launch (in October 1994), where they would spend 3 weeks undergoing 78 hours of training and data collection in addition to the 38 hours of training for Shuttle operations (Figure 1). All remaining crew training and baseline data collection would be conducted in Russia, primarily at the Gagarin Cosmonaut Training Center (Figure 2) and the Institute for Biomedical Problems, respectively.

Russian specialists from the Gagarin Cosmonaut Training Center and Institute for Biomedical Problems were familiarized with the planned in-flight investigations at the Johnson Space Center

in February and March 1994. Sessions included presentation of the scientific aims, basic principles, and equipment associated with experiments in seven program areas —metabolism, cardiovascular and respiratory function, sensory-motor and neuromuscular adaptation, sanitary-hygienic and radiation safety conditions, behavior and performance, fundamental biology, and microgravity. The equipment for these experiments was delivered to the Gagarin Cosmonaut Training Center, where cosmonauts and astronauts were to be trained to conduct the experiments, to service and operate the equipment, and procedures for controlling off-nominal situations.

Postflight Rehabilitation Plans

The need for a postflight rehabilitation period after the Mir-18 mission required detailed discussion and negotiations. The Mir-18 crew was scheduled to return to Earth on the Space Shuttle to a landing site in the U.S.; the U.S. side had not dealt with postflight rehabilitation after long flights since the Skylab program in the early 1970s. A program of rehabilitation measures that accounted for return on the Space Shuttle was developed by members of the Gagarin Cosmonaut Training Center in October 1994 and received final approval in April 1995. This integrated program was designed to ensure the crewmembers a period of medical rehabilitation, including procedures for monitoring their health and psychological state, while simultaneously meeting other needs of the program.

Specifically, the concepts underlying the plan for postflight crew activity were to support crew health and safety; to complete the scientific investigations; and to allocate appropriate time for reporting and public relations activities. To achieve this, a daily routine was planned for each crew member, with the work day limited to 8 hours and 3 days off during the first 3 weeks after the flight. For maximum flexibility, and to account for each crew member's state of health while meeting programmatic needs, it was considered advisable to use all of medical information obtained (i.e., from both the scientific experiments and the medical monitoring) to optimize medical rehabilitation and to plan crew activity. A brief medical examination was to be conducted every morning by the flight surgeons; at the end of each working day, that day's results were to be considered and a decision made as to subsequent postflight activities.

Phase 1 of the rehabilitation plan was expected to require 21 days (plus one backup day). The first stage involved landing and evacuation from the Space Shuttle (i.e., before the crew arrived at Johnson Space Center); the second stage, days 1-5 after landing, was to take place while the crew was living in the Johnson Space Center Crew Quarters; the third stage, days 6-21 + 1, was to take place while the crew lived off the space center campus.

Both U.S. and Russian flight surgeons were expected to have access to the crew after STS-71 landed; because the evacuation plan for the crews of STS-71 and Mir-18 called for the use of separate means of transport, flight surgeons from both countries were to be with the Mir-18 crew. Launch-and-entry suits were to be doffed and Kentavr anti-G suits donned.

The second and third stages of the rehabilitation period were to involve Russian and American flight surgeons being in constant contact with the crew for the first 5 days after return. Medical investigations and experiments were to be carried out in various buildings at Johnson Space Center, each of which was to be equipped for rendering emergency first aid with an ambulance on standby for the entire period of the investigations. Procedures were also developed for rehabilitation, for psychological observation and support during the rehabilitation period, for providing food and nutritional monitoring for 21 days, and for rendering outpatient and inpatient medical assistance as necessary.

Conclusions

This preliminary cooperative effort was a valuable opportunity for Russian and American medical support personnel to learn about space medicine and about working with each other. Many issues were raised for consideration; significant differences in approach were resolved through building a framework for discussion and negotiations, a process that has remained viable over time. Most of the preflight training for the Shuttle-Mir missions was conducted in Russia; postflight monitoring of crew health was carried out using facilities in Russia and the United States, with the participation of flight surgeons from both countries. The experience gained through the Shuttle-Mir and NASA-Mir programs will be invaluable for future collaborations during the International Space Station program.

Table 1. Tests proposed by Russian Main Medical Board to Certify U.S. Astronauts for Flight on Shuttle-Mir Missions

Clinical Tests (to be conducted in the U.S.)	Functional Tests (to be conducted in Russia)
<p>Contrast urography</p> <p>Endoscopy of the upper GI tract</p> <p>Sonographic examinations of the</p> <ul style="list-style-type: none"> • internal organs • genitourinary system • thyroid <p>Gynecologic examination*</p> <p>CT, MRI, or X-ray studies of the cervical, thoracic, and lumbar spine†</p> <p>CT, MRI, or X-ray studies of the nasal sinus cavities†</p> <p>24-hour Holter monitoring under ambulatory conditions</p>	<p>Altitude chamber investigations</p> <p>Vestibular tests on rotating chair</p> <p>Cycle ergometry (prone position) up to 85% of maximum workload</p> <p>Tilt-table tests at -15°, -30°, and $+70^{\circ}$</p> <p>Centrifuge tests (up to 5 Gz [head-to-pelvis] and 8 Gx (chest-to-back))</p>

*for women

†during the past 5 years

Figure Legends

Figure 1. Mir-18 Flight Engineer Gennadiy M. Strekalov practicing emergency egress from the Space Shuttle at Johnson Space Center in Houston.

Figure 2. Cosmonauts Gennadiy Strekalov and Vladimir Dezhurov and Astronaut Norman Thagard during Soyuz transport vehicle training at the Gagarin Cosmonaut Training Center in Star City.