Section 11 - Science Program

Authors:

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11.1 Introduction

11.1.1 Rules and Responsibilities

11.1.1.1 U.S. and Russian

The relationship between the parties for the purposes of research program implementation was governed by US/R-001.

The primary document describing the scope of the team's work within each increment was the Increment Payloads Requirements Document (IPRD) developed by the MSWG-4.

Based on the above documents the U.S. party undertook:

- to develop the flight, training, and test hardware as well as the relevant operating and test documents;
- to formulate the program and the requirements as to the performance of each of the experiments;
- to ensure hardware testing;
- to develop drawings and electrical diagrams;
- to train the crew at NASA centers;
- to develop the experiment procedures;
- to secure concurrence as to the flight data files;
- to participate in the testing of the hardware in Russia;
- to participate in the experiment planning;
- to deliver the hardware to the station aboard the Orbiter.

The Russian party provided for:

- a feasibility assessment of the proposed program;
- the concurrence of hardware documents;
- hardware integration to the station systems;
- participation in acceptance testing (AT) and the incoming inspection of the hardware in the United States;
- the logistics of the AT and incoming inspection in Russia;
- the development of the flight data files;
- crew training in Russia;
- the collection of pre- and postflight data in Russia;
- experiment planning and in-flight implementation;
- data acquisition aboard and transmission from the station;
- the delivery of the hardware to the station using the Progress and Soyuz vehicles.

The schedules for the data exchange and hardware deliveries were defined in Document US/R-002.

The Russian party's primary task was to evaluate the safety of the U.S. hardware with regard to its utilization aboard the *Mir* station.

Considering the commercial nature of the project, Russian experts were not involved in setting experiment objectives, experiment result analysis, or validity evaluations except as regards experiments to assess *Mir* parameters and those where Russian researchers were invited to participate by the U.S. party.

In addition, Russian experts performed pre- and postflight data collection in Russia.

11.1.1.2 WG-4 and WG-6

Science program activities were supported by two WGs:

- WG-4: Mission Science WG;
- WG-6; *Mir* Operations and Integration WG.

WG-4 concentrated on developing the science program and processing the results while WG-6 dealt with developing the hardware, the documentation, crew training, hardware testing and integration on board the station, in-flight research, and data acquisition.

Normally, all issues were discussed at joint team meetings held 4 times a year.

11.1.2 Resources

An extensive research program has been implemented in the course of 6 missions performed under Contract NAS15-10110.

To support the program the Russian party was to allocate considerable resources to accommodate the mass of U.S. cargoes (up to 2, 360 kg aboard the station at any one time), the power requirement (up to 2 kW average per day), and crew time (up to 70% of the U.S. astronaut's duty time and 30% of the Russian cosmonaut's duty time).

The actual program proposed by the U.S. party required less power (up to an average of 1.5 kW) and cosmonaut time (up to 17%) but exceeded the agreed-to mass limitations. In addition, the Russian party provided for the delivery of U.S. cargoes by Soyuz and Progress vehicles, which had not been a contract provision.

At the program development and implementation stages the parties worked together in the spirit of mutual understanding without resorting to undue formality, thereby promoting overall activity success.

11.1.3 Program Overview

On the whole the program has been completed, although there was a shortfall with regard to NASA-5 because of the accident on the Spektr module, postponement of NASA-6 experiments, and cancellation of a number of sessions for medical reasons. Nonetheless, results have been obtained in virtually all the planned experiments.

A number of steps taken by the parties to achieve a consensus on issues of experiment setup and implementation aboard a space vehicle were conducive to program completion.

It was early in the course of flights under the *Mir*-Shuttle program that the U.S. party recognized that it was impossible to run a rigid preplanned timeline to cover the entire duration of a long spaceflight and adopted the Russian method of design (preflight) and real-time (in-flight) planning.

This approach allowed the introduction of new sessions for the purposes of hardware repairs and recovery, adjustment of experiment procedures, change in operation times, etc.

In its own turn because of time constraints, the Russian party agreed to depart from the principle of having experiment procedures developed by Russian experts, which saved some time but reduced the scope of documentation monitoring by principal investigators.

Russian researchers that had an active role in experiment preparation and result assessment have obtained new data in space medicine, biology, and developed a number of systems to evaluate the station's operating parameters.

11.2 Mission Science Working Group (WG-4)

11.2.1 WG-4 History

The Mission Science Working Group (MSWG) was established in July 1992 as WG-4 in the overall joint Shuttle/*Mir* WG structure, following the U.S.-Russian agreement for expanded cooperation in human spaceflight. The initial agreement called for the flight of a Russian cosmonaut aboard the U.S. Space Shuttle, the flight of a U.S. astronaut aboard the Russian Space Station *Mir*, and the docking of the U.S. Space Shuttle with the Russian Space Station *Mir*. WG-4 was tasked to develop a cooperative science program, primarily in the Life Sciences, as part of these joint missions. The scope of the joint activities was expanded in November 1993 with the addition of four more long-duration flights of U.S. astronauts aboard *Mir* and up to nine additional Shuttle dockings with *Mir*. The U.S. would also provide life and microgravity science hardware to be installed in the Spektr and Priroda modules. The research program was expanded to include other science disciplines. In December 1995, two additional long-duration missions of U.S. astronauts aboard *Mir* were agreed to. WG-4 was given responsibility for developing and managing the science requirements of this expanded research program.

11.2.2 WG-4 Responsibilities

The MSWG had the primary overall responsibility for managing the research requirements in the Phase 1 program. Throughout preflight planning, in-flight operations, and postflight closeout, the MSWG was the intermediary interface between the experiment disciplines representing the requirements of the Principal Investigators (PIs) and the various experiment implementation organizations and processes. These included NASA Headquarters and the Program Office Management; Configuration Control Boards; the Training, Integration, and Operations groups; and the science discipline groups made up of payload developers. During the Phase 1 program, approximately 150 PIs were represented by seven research disciplines: Advanced Technology, Earth Sciences, Fundamental Biology, Human Life Science, International Space Station (ISS) Risk Mitigation, Microgravity, and Space Sciences. (See Attachment 11.2 for the list of PIs and associated investigations.)

As part of this process, the MSWG was responsible for ensuring science requirements are clearly defined and documented for implementation. This involved the development and management of requirements documents, such as the jointly agreed IPRD used during Phase 1B and the STS-71/Spacelab-*Mir* Mission Science Requirements Document, a U.S.-only document. Due to frequent changes in mission resource allocations and operational constraints, these documents were updated as appropriate through configuration controlled changes to the baselined science requirements. Mission Science had the responsibility to resolve any resource conflicts among the various disciplines and investigations, and during flight operations to actively participate in the replanning process.

The MSWG was also involved in various WG meetings and flight readiness activities. Periodic joint meetings with the investigator teams, including as appropriate, international partners in the mission research, were held to review the science requirements and their proposed implementation as defined in operations products, address mission critical issues, and establish working protocols. At the start of each mission, readiness reviews were held to discuss and resolve any science or operations problems that would potentially delay or impact the success of the mission.

In support of mission preparation and implementation, the MSWG also developed informational packages for release to the public through the NASA Public Affairs Office, press briefings, brochures, web sites, and symposia.

After flight, Mission Science had the responsibility for assessing the operational and science success of each mission and ensuring that the PIs reported on the results of the experiments. The science results were tracked through direct reporting from the PIs, at science symposia and through tracking the PIs' publications and public presentations.

11.2.3 WG-4 Structures and Processes

Throughout each increment, and across the Phase 1 program, Mission Science coordinated with the Discipline Leads to ensure successful implementation of the research objectives of the Phase 1 program and the objectives of each individual PI.

For each increment, a set of science requirements were entered into a computerized database, the Payload Integration Planning System (PIPS), and established through baselining of its product, the IPRD, at the *Mir* Operations and Integration Working Group (MOIWG) configuration control board. The U.S. requirements were then reviewed with Russian counterparts of both MSWG and MOIWG to assure that they were within resource constraints. Periodic revisions were distributed based on updates agreed upon during these joint meetings. The Final IPRD, usually released three months prior to the start of each increment, was then used as the guiding document for operations planning and real-time implementation.

The MOIWG also used the PIPS database for hardware management and used the IPRD in developing operations products for mission implementation. Whereas the MOIWG had increment specific teams dedicated to premission planning, real-time operations, and postmission closeout, the MSWG maintained a core team that worked throughout all aspects of the Phase 1 research program, both at the management and research discipline level. Mission Science coordinated with the MOIWG and supported mission implementation functions as part of the Houston Mission Control Center (MCC-H) Payload Operations Support Area (POSA) and the *Mir* Operations Support Team (MOST) or U.S. Consultants Group in the TsUP (Russian Mission Control Center) in Korolyov.

During real-time science implementation, replan requests (RR), generated by the discipline teams or operations implementation members, were written to document requested changes. Specialists in the POSA, composed of a science and operations team, evaluated the RRs for implementation feasibility. If these changes were outside the scope of the requirements documented in the Final IPRD, the RR was attached to a change request for disposition through the MOIWG configuration control board. The PIPS database was updated with approved change requests throughout the course of the mission. Approved changes were sent over to the TsUP and negotiated with the Russian side as changes to the Russian Final IPRD. Once successfully negotiated, the Form 24 (Russian Timeline) was updated with the requested inputs. At the end of the mission, the Final IPRD represented what was planned for implementation. The RR attachments plus the Final IPRD represented what was actually implemented.

11.2.4 Results Processing

The goal of work in research of the *Mir*-NASA Project scientific program was to perform operations to support and supply the American scientific research of the *Mir*-NASA Project.

The operational objectives were:

1. A scientific methodological examination of American research, including biomedical ethics issues.
2. Ground preparation and certification of equipment and hardware for flight research.
3. Pre- and postflight data collection as part of the biomedical research program.
4. Training and ground following of the flight portion of experiments.
5. Participation in the preparation and performance of fundamental biological research.
6. Supporting ground following of experiments by Russian specialists at MCC.

In contrast to the previous stage of Russian-American scientific cooperation under the *Mir*-Shuttle program, the microgravity, biomedical, and fundamental biological research programs included suggestions which had been selected by an independent U.S. peer review panel, and the Russian side became familiar with them after the selection.

The American proposals which had passed a scientific review were presented to the Russian side in the form of a list of experiments and brief information about the research process, the equipment used, and crew time requirements. During the course of discussions between the Russian and American specialists, the feasibility of conducting the experiments in space was evaluated and the possibilities for pre- and postflight examinations of Russian cosmonauts and American astronauts were agreed to. The Russian specialists suggested combining a number of research projects into a single procedure, which would allow resources and time to be saved and would simplify crew member training.

As a result of the discussions, the Russian and American sides came to the agreement that for each of the experiments co-executors would be appointed from the Russian side who would ensure following the experiments in all stages of their preparation and implementation. The co-executors would integrate the requirements of the Russian national science program with the American research to avoid duplication and obtain valid scientific results which might be used by the partners in accordance with the special agreements for each separately performed experiment.

The joint work of the Russian and American scientists frequently led to significant modification of the American proposals. It made the proposal more realistic and adaptable to crew activity conditions during extended spaceflight. On a number of the proposals, the American scientists backed away from their initial requirements or simplified them.

The Russian co-executors prepared and presented materials for the Russian Academy of Sciences Biomedical Ethics Commission. Members of the Commission performed a great deal of preliminary work in standardizing the techniques for evaluating the risk of conducting the research with the help of people from the American Biomedical Ethics Commission. A single form of informed consent for performing research involving humans was developed and agreed to, which is used when preparing materials for cosmonauts of both sides. As a result of the commission’s work, biomedical and fundamental biological research programs for the *Mir*-NASA project missions were approved.

The results of the agreements were outlined in the IPRD, which was really almost the implementation plan for the science documents. The IPRD addressed the issues of training astronauts and cosmonauts, performing pre- and postflight sessions, and the plan for transferring hardware from the Shuttle to *Mir* and returning hardware and experiments materials. Flight sessions were also addressed in the IPRD.

The Russian specialists took part in training the Russian crew members during the familiarization sessions at Johnson Space Center (JSC), as well as at Star City. The Russian specialists took part in preparing the procedures for performing the experiment, which were the prototype for the documentation for teaching cosmonauts and implementing the experiments during flight. Participation in preparing the flight data files also included:

- writing instructions for operating hardware;
- making corrections to preliminary versions of the flight data files;
- confirming the flight-ready version of the flight data files.

Long-term and detailed planning of the research took place with the participation of the Russian specialists who were responsible for performing individual experiments and the members of the MCC medical group. In addition, they prepared radiograms on experiment procedures, held radio conversations with the crew before and during the experiment, and held consultations on repairing hardware (if necessary).

At this stage of performing the research, the Russian specialists interacted with the American specialists in the Consulting Group at MCC. During this interaction, the procedures for performing the experiments were refined and the programs were corrected if necessary. Reasons for decreasing the quantity of research while it was being performed were:

- hardware malfunctions;
- medical restrictions;
- Spektr module depressurization;
- rescheduling of *Mir* service operations.

Problems that arose were regularly discussed in teleconferences between the American and Russian specialists, with management and leading project specialists participating.

The involvement of Russian specialists in the pre- and postflight observations in various experiments was not uniform, as some of them participated in the materials analysis and processing of results obtained.

The Russian scientists took part in gathering background data. In a number of cases they fulfilled service functions, and in other experiments they took on the role of co-executors, taking part in processing and analyzing data obtained.

The observations of Russian cosmonauts were called for by experiments with identical procedures in the American and Russian science programs, and were performed by Russian specialists per the agreed-upon protocols.

The degree of participation by Russian scientists was determined by preliminary agreements reached at meetings of the Joint Working Group. The partners exchanged data on the research in accordance with agreements reached at meetings of Russian and American specialists.

The problems which arose during the course of the experiments were resolved quickly by the scientists with the cooperation of the MCC Consulting Group and Russian specialists responsible for planning.

11.2.5 WG-4 Accomplishments

The challenges to the successful completion of the Phase 1 research program during its relatively brief history are too numerous to list in this report. Among a few major ones are: the compressed development schedule; the two sides learning to work together; overcoming language barriers; the U.S. team learning the "culture" of long-duration spaceflight; and replanning of the research program in the face of significant and ever-changing operational constraints. With the representation of accomplishments listed in this section, it is clear that the Phase 1 research program has overcome these challenges, yielding a wealth of new information and, as always in scientific endeavors, raising many new questions. It will be several more years before the full scope of what was accomplished and learned can be fully appreciated.

The 10 long-duration *Mir* missions and 7 long-duration NASA missions, as well as the 9 Shuttle-*Mir* docking Shuttle missions, resulted in a wealth of station research experience, samples, data, and science return for the approximately 100 unique *Mir*-based investigations, representing approximately 150 investigators, that were conducted during the NASA-*Mir* Research Program. Seven U.S. astronauts and 17 Russian cosmonauts, three of whom were involved in two Phase 1 missions, participated in the long-duration research program. The actual number of investigations per research discipline is supplied in Table 11.1, some of which were flown over multiple increments.

Number of Long-Duration Investigations per Discipline

Table 11.1

Research Discipline	Research Increment						
	1	2	3	4	5	6	7
Advanced Technology		1	2			1	3
Earth Sciences		2	2	2	3	3	3
Fundamental Biology	1	3	2	4	5	1	
Human Life Sciences	26	11	12	8	6	5	6
ISS Risk Mitigation		5	7	8	7	6	2
Microgravity	1	12	10	11	9	9	8
Space Sciences		2	2	2			
Total Investigations	28	26	37	35	30	25	22

Reference Attach. 11.3 for the table of investigations flown on each Phase 1 increment.

The *Mir* station provided many U.S. investigators, whose previous experiences included only short-duration Shuttle missions, their first experience with a long-duration platform as a test bed for facilities and experiment protocols planned for use on ISS. International participation in the Phase 1 research program included investigators from the United States, Russia, Canada, the United Kingdom, Japan, Germany, France, and Hungary.

Advanced Technology investigators used the weightless environment of *Mir* to study basic physical processes and generate better quality and new alloys, with multiple industrial and scientific applications.

The three-year near-continuous observations of Earth phenomena by trained crew members has added tens of thousands of images to the exciting database of Earth imagery and to researchers' understanding of long-term changes, both ephemeral natural and human induced, and for the first time documented global baseline conditions leading up to and through the 1997 El Niño.

Documentation during this timeframe on *Mir* demonstrated for the first time the northwestward drift of the South Atlantic Anomaly through comparison between Skylab and *Mir* data.

Fundamental Biology investigations yielded highly successful plant growth experiments resulting in the most biomass ever grown in space and the first plants grown from seeds developed entirely in space.

The Human Life Sciences study of crew members before, during, and after long-duration flight has led to a better understanding of the physiological and psychological effects of long-duration spaceflight. The NASA-*Mir* program has seen the documentation of space-induced changes in human body systems such as the immune system, cardiac functions, circadian rhythms, renal functions, and bone and mineral metabolism.

Mir operations and risk mitigation experiments have contributed significantly to our understanding of long-duration spaceflight and resulted in modifications to ISS planning, design, and operations. The structural dynamics and micrometeoroid impact experiments are two examples of demonstrations of crew and vehicle microgravity disturbances and interactions as well as how materials and structures respond to long exposures to the low Earth orbit environment.

Microgravity discipline supported science has extended the duration of tissue culture experiments from 14 days to 4 months in orbit developing 3-dimensional tissue cultures. Tissue constructs such as these are difficult to generate on Earth and have great potential for applications in orthopedic and cosmetic surgery. In addition, new techniques for growing protein crystals in space have been established with qualitative and quantitative improvements over ground-based activities. Analyses of these high-quality crystals are leading to advances in pharmacology and molecular biology.

The discovery of extraterrestrial particulates in the aerogels contained in the Space Sciences experiment collector trays clearly demonstrates that many cosmic dust particles can be returned to Earth for physical and chemical analysis.

Following each Phase 1 mission, each U.S. PI was required to submit to Mission Science a postflight Operational Accomplishments Report (R+30 days), a Preliminary Research Report (R+180 days), and a Final Research Report (R+1 year), outlining their research status and preliminary conclusions. To date, a total of 237 postflight research reports have been received, archived, and distributed by Mission Science. Attachment 11.4 contains the table of contents for each document published to date of these reports. Also, many PIs have published their Phase 1 research findings in peer-reviewed publications, and these are listed in Attachment 11.5.

The MSWG has also organized Research Results Symposia in which investigators have participated by sharing data between similar research areas and presentation of results to date. These types of forums have supplied NASA management, the Phase 1 crew members, and the participants of the Phase 1 research program with the results and successes of the numerous experiments conducted during the program. The first symposium, held at JSC in August 1997, focused primarily on experiments from the NASA-2 and NASA-3 missions. The second meeting, held in April 1998 at Ames Research Center, focused mainly on the NASA-4 and -5 missions. A third symposium targeted for November 1998, at Marshall Space Flight Center, will close out those experiments conducted throughout the program and will focus on the NASA-6 and -7 missions. Two symposia proceedings packages, a compilation of 82 Phase 1 experiment presentations, have been distributed and the table of contents of these can be found in Attachment 11.6.

11.2.6 Lessons Learned

The 10 most important lessons learned from the Phase 1 Research Program are listed below. Clearly, many if not all will have application in the successful conduct of the research program on ISS.

1. **Develop and implement a realistic schedule from experiment solicitation to flight.**
The 2-year experiment solicitation-to-flight schedule for Phase 1 was inadequate to ensure proper definition and implementation of all selected experiments without significant challenges. The lack of early definition of the research had multiple impacts to proper implementation of the experiments.

2. **Plan for a realistic complement of experiments for each long-duration mission to achieve specific scientific objectives.**
Provide a narrower focus for each increment and plan the research program accordingly (quality vs. quantity).

3. **Maintain clear distinction between science requirements (PI-generated) and science operations (guided by operational constraints).**
Science "requirements" were often changed to accommodate operational constraints; in truth, the requirements did not change, only their implementation.

4. **Ensure full coordination between experiments and facilities, hardware and software interfaces, in ground testing, training, etc.**
There were instances where incompatibilities were uncovered only in flight; this was usually due to inadequate time for preflight preparation.

5. **Ensure that training is performed in full-up configuration, with all experiment components.**
There were instances where the first time a crew member did an end-to-end experiment session was on orbit.

6. **In scheduling science activities, all overhead must be accounted for.**
Performing a science session usually requires additional time that initially was not accounted for, potentially leading to crew overwork. These ancillary activities include, but are not limited to, on-orbit refresher training; search for and identification of all required hardware items; evolving crew familiarity with the experiment; experiment setup; experiment stow.

7. **Develop a single hardware manifest.**
There were multiple manifests maintained by different organizations, with different purposes and authorities, often leading to confusion.

8. **Develop a single hardware/safety documentation system for all payload carriers.**
Hardware developers were often swamped in submitting essentially the same information to different organizations in different formats.

9. **With limited voice communication with the crew, rely more on E-mail.**
In many cases, use of E-mail allows for more thorough communication between the crew member and the ground support team.

10. **Understand the cultural differences between short-duration and long-duration flight and their interactions.**
These are in the areas of training, operations, manifesting, etc. Many of these factors are not unique to *Mir*, but are a reflection of operating in a long-duration environment, regardless of the specific platform.

11. **During selection of experiment, the management team should pay special attention to reviewing of biomedical studies to maximize crew member acceptability.**

11.2.7 WG-4 Summary

The Phase 1 Research Program offered many U.S. investigators their first opportunity to conduct research in a long-duration environment. This invaluable experience gained not only by the investigators but also by the U.S. and Russian ground support teams, in addition to the actual scientific return from the program, will be a tremendous aid in conducting similar research on ISS. From a research perspective, Phase 1 was clearly a worthwhile endeavor.

List of Phase 1 Principal Investigators and Their Experiments

Attach. 11.2

<u>Phase 1A</u>

Metabolic Research:	U.S. Investigator(s)	Russian Investigator(s)
Fluid and Electrolyte Homeostasis and its Regulation	Helen Lane, Ph.D.	Anatoly Grigoriev, M.D.
Dynamics of Calcium Metabolism and Bone Tissue	Helen Lane, Ph.D.	V. Ogonov, M.D., Ph.D. Irina Popova, Ph.D.
Renal Stone Risk Assessment	Peggy Whitson, Ph.D.	German Arzamozov, M.D. Sergey Kreavoy, M.D.
Metabolic Response to Exercise	Helen Lane, Ph.D.	Irina Popova, Ph.D.
Metabolism of Red Blood Cells	Helen Lane, Ph.D.	Svetlana Ivanova, Ph.D.
Red Blood Cell Mass and Survival	Helen Lane, Ph.D.	Svetlana Ivanova, Ph.D.
Physiologic Alterations and Pharmacokinetic Changes During Spaceflight	Lakshmi Putcha, Ph.D.	I. Goncharov, Ph.D.
Humoral Immunity	Clarence Sams, Ph.D.	Irina Konstantinova, M.D.
Viral Reactivation	Duane Pierson, Ph.D.	Irina Konstantinova, M.D.
Peripheral Mononuclear Cells	Clarence Sams, Ph.D.	Irina Konstantinova, M.D.
Cardiovascular and Pulmonary Research:		
Studies on Orthostatic Tolerance With the Use of LBNP	John Charles, Ph.D.	Valeriy Mikhaylov, M.D.
Studies of Mechanisms Underlying Orthostatic Intolerance Using Ambulatory Monitoring Baroflex Testing and Valsalva Maneuver	Janice Yelle, M.S. John Charles, Ph.D.	Valeriy Mikhaylov, M.D.
Maximal Aerobic Capacity Using Graded Bicycle Ergometry	Steven Siconolfi, Ph.D. Suzanne Fortney, Ph.D.	Valeriy Mikhaylov, M.D. Alexander Kotov, M.D.
Evaluation of Thermoregulation During Spaceflight	Suzanne Fortney, Ph.D.	Valeriy Mikhaylov, M.D.
Physiological Response During Descent of Space Shuttle	John Charles, Ph.D.	Valeriy Mikhaylov, M.D.
Neurosensory Research:		
Evaluation of Skeletal Muscle Performance & Characteristics	Steven Siconolfi, Ph.D. John McCarthy, Ph.D.	Inessa Kozlovskaya, M.D. Yury Koryak, Ph.D. N.M. Kharitonov, Ph.D.
Morphological, Histochemical & Ultrastructural Characteristics of Skeletal Muscle	Daniel Feeback, Ph.D.	Boris Shenkman, Ph.D.
Eye-Head Coordination During Target Acquisition	M. Reschke, Ph.D. J. Bloomberg, Ph.D. W. Paloski, Ph.D.	I. Kozlovskaya, M.D. L. Kornilova, M.D. V. Barmin, M.D. A. Sokolov, M.D. B. Babayev, M.D.
Posture and Locomotion	J. Bloomberg, Ph.D. W. Paloski, Ph.D. M. Reschke, Ph.D. D. Harm, Ph.D.	I. Kozlovskaya, M.D. A. Voronov, Ph.D. I. Tchekirda, M.D. M. Borisov
Hygiene, Sanitation, and Radiation Research:		
Microbiology	Duane L. Pierson, Ph.D. Richard Sauer, P.E.	Natalia Novokova, Ph.D. Vladimir Skuratov, M.D.
In-Flight Radiation Measurements	G.D. Badwhar, Ph.D.	Vladislav Petrov, Ph.D.
Measurement of Cytogenetic Effects of Space Radiation	T.C. Yang, Ph.D.	B. Fedorenko, Ph.D.
Trace Chemical Contamination	John James, Ph.D. Richard Sauer, P.E.	L. Mukhamedieva, M.D. Yuri Sinyak, Ph.D.

List of Phase 1 Principal Investigators and Their Experiments (continued)

Phase 1A continued

Behavior and Performance Research:		
The Effectiveness of Manual Control During Simulation of Flight Tasks (PILOT)	Deborah L. Harm, Ph.D.	V.P. Salnitskiy, Ph.D.
Fundamental Biology Research:	**U.S. Investigators**	**Russian Investigator**
Incubator	Biospeciman Sharing Program	T.S. Guryeva, Ph.D. Olga Dadasheva, Ph.D.
Greenhouse	Frank Salisbury, Ph.D. Gail Bingham, Ph.D.	M. A. Levinskikh, Ph.D.
Microgravity Research:		
Space Acceleration Measurement System (SAMS)	Richard DeLombard	S. Ryaboukha, Ph.D.
Protein Crystallization Methods	Stan Koszelac, Ph.D. Alexander Malkin, Ph.D.	O. Mitichkin, Ph.D.

Phase 1B

Advanced Technology:	**U.S. Investigator(s)**	**Russian Investigator(s)**
Optizone Liquid Phase Sintering	James Smith, Ph.D.	
Materials in Devices and Superconductors	Stephanie Wise Ruth Amundsen	Yuri Grigorashvili Svyatoslav Volkov Eugene Vasilyev Vladimir Koshelev
Commercial Protein Crystal Growth	Larry DeLucas	
Commercial Generic Bioprocessing Apparatus	Louis Stodieck	
Liquid Motion Experiment	Richard Knoll	
ASTROCULTURE	Raymond Bula	
X-Ray Detector Test	Larry DeLucas	
Earth Sciences:		
Calibration & Validation of Priroda Microwave Sensors	James Shiue, Ph.D.	Neon Armand, Ph.D.
Comparison of Atmospheric Chemistry Sensors on Priroda and American Satellites	Jack Kaye	
Regional & Temperature Variability of Primary Productivity in Ocean Shelf Waters	F.E. Muller-Karger O. Kopelevich	
Test Site Monitoring & Visual Earth Observations	Kamlesh Lulla, Ph.D. Cynthia Evans, Ph.D.	Lev Desinov, Ph.D.
Validation of Biosphere-Atmosphere Interchange Model for Northern Prairies	A. W. England Anatoly Shutko	
Validation of Priroda Rain Observations	Otto Thiele	
Fundamental Biology:		
Incubator-Integrated Quail Experiments on *Mir*	Gary W. Conrad, Ph.D. Cesar D. Fermin, Ph.D. Stephen B. Doty, Ph.D. Bernd Fritzsch, Ph.D. Patricia Y. Hester, Ph.D. Peter I. Lelkes, Ph.D. Page A. W. Anderson, M.D Bernard C. Wentworth, Ph.D. Toru Shimizu, Ph.D.	Olga Dadasheva, Ph.D. Tamara Gurieva, Ph.D.

List of Phase 1 Principal Investigators and Their Experiments (continued)

<u>Phase 1B continued</u>

Fundamental Biology Continued:	**<u>U.S. Investigators</u>**	**<u>Russian Investigators</u>**
Environmental Radiation Measurements	Eugene Benton, Ph.D.	
Greenhouse-Integrated Plant Experiment	Frank Salisbury, Ph.D. Gail Bingham, Ph.D. John Carman, Ph.D. William Campbell, Ph.D. David Bubenheim, Ph.D. Boris Yendler, Ph.D.	M. Levinskikh, Ph.D.
Effective Dose Measurements	Sandor Derne. Ph.D.	Yuri Akatov
Cellular Mechanisms of Spaceflight Specific to Plants	Abraham. D. Krikorian	
Standard Interface Glovebox	Paul D. Savage	
Developmental Analysis of Seeds Grown on *Mir*	Mary Musgrave, Ph.D.	Margartia Levinskikh
Effects of Gravity on Insect Circadian Rhythmicity	T. Hoban-Higgins, Ph.D.	Alexei Alpatov
Active Dosimetry of Charged Particles	Jobst Ulrich Schott	
Human Life Sciences:		
Analysis of Volatile Organic Compounds on *Mir*	Peter Palmer. Ph.D.	Valentina Savina, M.D.
Anticipatory Postural Activity	Jacob Bloomberg, Ph.D.	Inessa Kozlovskaya, M.D.
Assessment of Humoral Immune Function	Clarence Sams, Ph.D.	A. T. Lesnyak
Bone Mineral Loss & Recovery	Linda Shackelford, M.D.	V. Oganov, M.D., Ph.D.
Collecting *Mir* Source & Reclaimed Waters	Richard L. Sauer, P.E.	Yuri Sinyak, Ph.D.
Crew Member & Crew-Ground Interactions	Nick A. Kanas, Ph.D.	Vyacheslav Salnitskiy
Evaluation of Skeletal Muscle Performance & Characteristics	S. F. Siconolfi, Ph.D.	Inessa Kozlovskaya, M.D.
Gas Analyzer System Metabolic Analysis Physiology	Floyd Booker	
Magnetic Resonance Imaging After Exposure to Microgravity	Adrian LeBlanc, Ph.D.	Inessa Kozlovskaya, M.D.
Microbiological Interaction in the *Mir* Space Environment	George M. Weinstock	A. Viktorov, Ph.D.
Protein Metabolism	T. Peter Stein, Ph.D.	Irina Larina, Ph.D.
Renal Stone Risk Assessment	Peggy Whitson, Ph.D.	Sergey Kreavoy, M.D. German Arzamazov, M.D.
Renal Stone Risk Assessment: Dried Urine Chemistry	Peggy Whitson, Ph.D.	Sergey Kreavoy, M.D.
Sleep Investigations	Allan Hobson, M.D. Timothy H. Monk, Ph.D. Harvey Moldofsky, M.D.	Irina Ponomareva, M.D.
Effects of Long-Duration Spaceflight on Eye, Head, & Trunk Coordination During Locomotion	Jacob Bloomberg, Ph.D.	Inessa Kozlovskaya, M.D.
Effects of Spaceflight on Gaze Control	Mill Reschke, Ph.D.	Inessa Kozlovskaya, M.D.
Frames of Reference for Sensorimotor Transformation	Alan Berthoz, Ph.D.	Victor Gurfinkel
Cardiovascular Investigations	C. Gunnar Blomqvist. M.D. Dwain Eckberg, M.D.	
International Space Station Risk Mitigation:		
Enhanced Dynamic Load Sensors on *Mir*	Sherwin Beck	
Mir Audible Noise Measurement	C. Parsons	
Mir Electric Field Characterization	Phong Ngo	
Mir Environmental Effects payload	Buck Gay	
Mir Wireless Network	Yuri Gawdiak	
Orbital Debris Collector	Freidrich Horz	
Passive Optical Sample Assembly #1 and #2	G. Pippin Jim Zwiener	
Polish Plate Micrometeoroid Debris Collector	W. Kinard	

List of Phase 1 Principal Investigators and Their Experiments (continued)

Phase 1B Continued

International Space Station Continued:	U.S. Investigators	Russian Investigators
Shuttle/*Mir* Alignment Stability Experiment	Russel Yates	S. Shitov, Ph.D.
Water Microbiological Monitor	Duane L. Pierson, Ph.D.	
Mir Structural Dynamics Experiment	Hyoung-Man Kim, Ph.D.	Vyacheslav Mezhin
Optical Properties Monitor	Don Wilkes	S. Naumov Sergey Demidov
Cosmic Radiation and Effects Activation Monitor	Peter Truscott	
Test of PCS Hardware	Rod Lofton	
Space Portable Spectroreflectometer	Ralph Carruth	Stanislov Naumov, Ph.D.
Radiation Monitoring Equipment	Mike Golightly Francis Afinidad	Vladislav Petrov
Microgravity:		
Biotechnology System Facility Operations	Steve Gonda, Ph.D.	
Binary Colloidal Alloy Test	David A. Weitz, Ph.D.	
Cartilage in Space	Lisa Freed, M.D., Ph.D. Steve Gonda, Ph.D.	
Biotechnology Diagnostic Experiment	Steve Gonda, Ph.D.	
Biotechnology Co-Culture	Elliot Levine, Ph.D. Thomas Goodwin	
Biochemistry of 3D Tissue Engineering	Timothy Hammond, Ph.D. Peter Lelkes, Ph.D.	
Candle Flame in Microgravity	Dan Deitrich	
Forced Flow Flamespread Test	Kurt Sacksteder. Ph.D.	
Opposed Flow Flamespread on Cylindrical Surfaces	Robert A. Altenkirch	
Interface Configuration Experiment	Mark Weislogel	
Liquid Metal Diffusion	Franz Rosenberger	
Mechanics of Granular Materials	Stein Sture, Ph.D. Nicholas Costes, Ph.D.	
Microgravity Glovebox Facility Operations	Don Reiss, Ph.D.	
Angular Liquid Bridge Experiment	Paul Concus, Ph.D.	
Microgravity Isolation Mount Facility Operations	Bjarni Trygvasson, Ph.D.	
Queen's University Experiment in Liquid Diffusion	Reginald Smith, Ph.D.	
Passive Accelerometer System	Iwan Alexander, Ph.D.	
Protein Crystal Growth GN2 Experiment	Alexander McPherson, Ph.D. Stan Koszelak, Ph.D.	
Diffusion Controlled Crystallization Apparatus	Dan Carter, Ph.D.	
Space Acceleration Measurement System	Richard DeLombard	Stanislav Ryaboukha
Technological Evaluation of Microgravity Isolation Mount (MIM)	Jeff Allen	
Colloidal Gelation	David Weitz, Ph.D.	
Canadian Protein Crystallization Experiment	Phillip Gregory	
Interferometer Protein Crystal Growth	Alexander McPherson, Ph.D.	
Space Sciences:		
Mir Sample Return	Peter Tsou, Ph.D.	
Particle Impact Experiment	Carl Maag, Ph.D.	

Attachment 11.3: Table of Phase 1 Investigations per Mission Increment

Phase 1A

Metabolic Research:	***Mir* 18/NASA 1**	**STS-71**	***Mir* 19**
Fluid and Electrolyte Homeostasis and its Regulation	X	X	
Dynamics of Calcium Metabolism and Bone Tissue	X	X	
Renal Stone Risk Assessment	X	X	
Metabolic Response to Exercise	X		
Metabolism of Red Blood Cells	X		
Red Blood Cell Mass and Survival	X		
Physiologic Alterations and Pharmacokinetic Changes During Spaceflight	X		
Humoral Immunity		X	X
Viral Reactivation	X		
Peripheral Mononuclear Cells		X	
Cardiovascular and Pulmonary Research:			
Studies on Orthostatic Tolerance With the Use of LBNP	X	X	
Studies of Mechanisms Underlying Orthostatic Intolerance Using		X	
Ambulatory Monitoring Baroflex Testing and Valsalva Maneuver	X	X	
Maximal Aerobic Capacity Using Graded Bicycle Ergometry	X	X	
Evaluation of Thermoregulation During Spaceflight	X		
Physiological Response During Descent of Space Shuttle		X	
Neurosensory Research:			
Evaluation of Skeletal Muscle Performance and Characteristics	X	X	
Morphological, Histochemical & Ultrastructural Characteristics of Skeletal Muscle	X		X
Eye-Head Coordination During Target Acquisition	X	X	X
Posture and Locomotion	X		X
Hygiene, Sanitation, and Radiation Research:			
Microbiology	X	X	X
In-flight Radiation Measurements	X	X	X
Measurement of Cytogenetic Effects of Space Radiation	X		
Trace Chemical Contamination	X	X	X
Behavior and Performance Research:			
The Effectiveness of Manual Control During Simulation of Flight Tasks (PILOT)	X		
Fundamental Biology Research:			
Incubator	X		X
Greenhouse			X
Microgravity Research			
Space Acceleration Measurement System (SAMS)			X
Protein Crystallization Methods		X	X

Attachment 11.3: Table of Phase 1 Investigations per Mission Increment (continued)

Phase 1B

	Research Increment					
Advanced Technology:	**2**	**3**	**4**	**5**	**6**	**7**
Optizone Liquid Phase Sintering	X					X
Materials in Devices as Superconductors		X				
Commercial Protein Crystal Growth		X				
Commercial Generic Bioprocessing Apparatus		X			X	
Liquid Motion Experiment				X		
ASTROCULTURE						X
X-Ray Detector Test						X
Earth Sciences:						
Calibration & Validation of Priroda Microwave Sensors	X*	X*	X*	X*	X*	X*
Comparison of Atmospheric Chemistry Sensors on Priroda and American Satellites	X*	X*	X*	X*	X*	X*
Regional & Temperature Variability of Primary Productivity in Ocean Shelf Waters	X*	X*	X*	X*	X*	X*
Test Site Monitoring & Visual Earth Observations	X	X	X	X	X	X
Validation of Biosphere-Atmosphere Interchange Model for Northern Prairies	X*	X*	X*	X*	X*	X*
Validation of Priroda Rain Observations	X*	X*	X*	X*	X*	X*
Mir Window Documentation				X	X	

* - Priroda sensors used to support these experiments were only partially activated

	2	3	4	5	6	7
Fundamental Biology:						
Environmental Radiation Measurements	X	X	X	X		
Incubator-Integrated Quail Experiments on *Mir*	X					
Greenhouse - Integrated Plant Experiments		X				
Effective Dose Measurement at EVA			X	X		
Cellular Mechanisms of Spaceflight Specific to Plants			X			
Standard Interface Glovebox			X			
Developmental Analysis of Seeds Grown on *Mir*				X		
Effects of Gravity on Insect Circadian Rhythmicity				X		
Active Dosimetry of Charged Particles					X	
Human Life Sciences:						
Effects of Spaceflight on Gaze Control	X					
Anticipatory Postural Activity	X					
Evaluation of Skeletal Muscle Performance & Characteristics		X				
Effects of Long-Duration Spaceflight on Eye, Head, & Trunk Coordination During Locomotion	X	X				
Assessment of Humoral Immune Function	X	X	X		X	X
Bone Mineral Loss & Recovery	X	X	X	X	X	X
Collecting *Mir* Source & Reclaimed Waters	X	X	X*	X*	X*	X*
Analysis of Volatile Organic Compounds on *Mir*	X	X	X*	X*	X*	X*
Microbiological Investigations of the *Mir* Crew		X	X*	X*	X*	X*
Gas Analyzer System Metabolic Analysis Physiology	X	X	X	X		
Magnetic Resonance Imaging After Exposure to Microgravity	X	X	X	X	X	X
Protein Metabolism	X	X				
Renal Stone Risk Assessment	X	X			X	X
Crew Member & Crew-Ground Interactions		X	X	X	X	X

Attachment 11.3: Table of Phase 1 Investigations per Mission Increment (continued)

<u>Phase 1B Continued</u>

	Research Increment					
Human Life Sciences Continued:	**2**	**3**	**4**	**5**	**6**	**7**
Sleep Investigations			X	X	X	
Frames of Reference for Sensorimotor Transformations			X	X		
Cardiovascular Investigations					X	X
* - performed under the Space Medicine Program (SMP)						
International Space Station Risk Mitigation:						
Mir Audible Noise Measurement	X					
Shuttle/*Mir* Alignment Stability Experiment	X	X				
Enhanced Dynamic Load Sensors on *Mir*	X		X		X	
Mir Electric Field Characterization	X	X	X			
Orbital Debris Collector	X	X	X	X	X	
Passive Optical Sample Assembly #1 and #2	X	X	X	X	X	
Polish Plate Micrometeoroid Debris Collector	X	X	X	X	X	
Water Microbiological Monitor		X	X	X*	X*	
Mir Structural Dynamics Experiment		X	X	X	X	
Optical Properties Monitor			X	X	X	
Cosmic Radiation and Effects Activation Monitor					X	X
Test of PCS Hardware					X	X
Space Portable Spectroreflectometer					X	
Radiation Monitoring Equipment					X	X
* - performed under the SMP						
Microgravity:						
Interface Configuration Experiment	X					
Candle Flame in Microgravity	X					
Forced Flow Flamespread Test	X					
Angular Liquid Bridge			X			
Opposed Flow Flamespread on Cylindrical Surfaces			X			
Binary Colloidal Alloy Test		X			X	
Passive Accelerometer System		X				
Biotechnology System Facility Operations	X	X	X	X	X	X
Biotechnology Diagnostic Experiment			X	X	X	
Cartilage in Space		X				
Biochemistry of 3D Tissue Engineering					X	
Biotechnology CoCulture						X
Mechanics of Granular Materials	X				X	
Microgravity Glovebox Facility Operations	X	X	X	X	X	
Microgravity Isolation Mount Facility Operations	X		X		X	X
Technological Evaluation of MIM	X					
Liquid Metal Diffusion			X			
Queen's University Experiment in Liquid Diffusion			X		X	X
Protein Crystal Growth GN2 Experiment	X	X	X	X		X
Diffusion Controlled Crystallization Apparatus	X	X	X	X		X
Space Acceleration Measurement System	X	X	X	X	X	X
Colloidal Gelation				X		
Canadian Protein Crystallization Experiment					X	
Interferometer Protein Crystal Growth					X	

Attachment 11.3: Table of Phase 1 Investigations per Mission Increment (continued)

Phase 1B Continued

Space Sciences:	**Research Increment** 2	3	4	5	6	7
Mir Sample Return Experiment	X	X	X			
Particle Impact Experiment	X	X	X			

Attachment 11.4: Phase 1 Postflight Reports

PHASE 1A

PUBLISHED MARCH 1998

Attachment 11.4: Phase 1 Postflight Reports Continued

PHASE 1B QUARTERLY 1
PUBLISHED MAY 1997

Attachment 11.4: Phase 1 Postflight Reports Continued

Phase 1B Quarterly 2

PUBLISHED AUGUST 1997

Attachment 11.4: Phase 1 Postflight Reports Continued

Phase 1B Quarterly 3

PUBLISHED JANUARY 1998

Attachment 11.4: Phase 1 Postflight Reports Continued

Phase 1B Quarterly 4

PUBLISHED MARCH 1998

Attachment 11.4: Phase 1 Postflight Reports Continued

PHASE 1B QUARTERLY 5
PUBLISHED JUNE 1998

Attachment 11.5: List of Phase 1 Peer-Reviewed Publications

Arzamazov, G. S., Whitson, P. A., Larina, O. N., Pastushkova, L. Kh., Pak, C. Y. C. “Assessment of the Risk Factors for Urolithiasis in Cosmonauts During Long Flights.” *Aviakosmicheskaia I Ekologicheskaia Meditsina* 30(3): 24-32, (1996).

Badhwar, G.D. “Drift rate of the South Atlantic Anomaly.” *J. Geophys. Res.,* Vol. 102, pp. 2343-2349, (Feb. 1997).

Badhwar, G.D. “The Radiation Environment in Low Earth Orbit.” Radiation Research, 148 (5 Suppl): S3-10, (1997).

Badhwar, G.D., Atwell, W., Cash, B., Petrov, V.M., Akatov, Y.A., Tchernykh, I.V., Shurshakov, V.A., and Arkhangelsky, V.A. “Radiation environment on the *Mir* orbital station during solar minimum.” *Adv. Space Res.,* (1997) (accepted for publication).

Badhwar, G.D., Cucinotta, F. A. “Depth Dependence of Absorbed Dose, Dose Equivalent and Linear energy Transfer Spectra of Galactic and Trapped Particles in Polyethylene and comparison with Calculations of Models.” *Radiation Research*, 149: 209-218, (1998).

Badhwar, V.A., Shurshakov, V.A., and Tsetlin, V.V. “Solar modulation of dose rate onboard the *Mir* station.” *IEEE Nucl. Science,* 1997 (submitted for publication).

Bingham, G.E., Salisbury, F.B., Campbell, W.F., and Carman, J.G. “The Spacelab- and *Mir*-1 ‘Greenhouse-2’ experiment.” *Microgravity Science and Technology*, 18(3):58-65, (1994).

Bingham, G.E., Salisbury, F.B., Campbell, W.F., Carman, J.G., Yendler, B.Y., Sytchev, V.S., Berkovich, Y.B., Levinskikh, M.A., and Podolsky, I. “The Spacelab-*Mir*-1 ‘Greenhouse-2’ Experiment.” *Adv. Space Res.* 18:225-232, (1996).

Fortney, S.M., Mikhaylov, V., Lee, S.M.C., Kobzsev, Y., Gonzalez, R.R., and Greenleaf, J.E. “Body Temperature and Thermoregulation After 115-Day Space Flight.” *Aviat. Space Environ. Med.* (**In Press**).

Freed, L.E., Langer, R., Martin, I., Pellis, N., and Vunjak-Novakovic, G. “Tissue Engineering of Cartilage in Space.” *Proc. Natl. Acad. Sci. USA*, Vol. 94, pp 13885-13890, (1997).

Attachment 11.5: List of Phase 1 Peer-Reviewed Publications (Continued)

Fritsch-Yelle, J. M., Leuenberger, U. A., D'Aunno, D. S., Rossum, A. C., Brown, T. E., Wood, M. D., Josephson, M. E., Goldberger, A. L. "An Episode of Ventricular Tachycardia During Long-Duration Spaceflight." *American Journal of Cardiology*, **in press** (1998).

Jones, S. B. and Or, Dani. "Microgravity Effects on Water Flow and Distribution in Unsaturated Poroud Media: Analysis of Flight Experiments." *Soil Science,* In press.

Koszelak, S., Leja, C., and McPherson, A. "Crystallization of Biological Macromolecules from Flash Frozen Samples on the Russian Space Station *Mir*." *Biotech. and Bioeng.,* Vol. 52, pp. 449-458, (1996).

Layne, C.S., Lange, G.W., Pruett, C.J., McDonald, P.V., Merkle, L.A., Smith, S.L., Kozlovskaya, I.B. and Bloomberg, J.J., "Adaptation of neuromuscular activation patterns during locomotion after long-duration space flight." *Acta Astronautica*, **in press**, 1998.

Layne, C.S., Mulavara, A.P., McDonald, P.V., Kozlovskaya, I.B., Pruett, C.J., and Bloomberg, J.J. "The effect of Foot Pressure on Neuromuscular Activation Patterns Generated During Space Flight." *J. Neurophys.,* **In Press** (revision), (1997).

Salisbury, F.B., Bingham, G.E., Campbell, W.F., Carman, J.G., Bubenheim, D.L., Yendler, B., Jahns, G. "Growing Super-Dwarf Wheat in Svet on *Mir*." *Life Support and Biosphere Science*, 2:31-39, (1995).

Sture, S., Costes, N. C., Batiste, S., Lankton, M., AlShibli, K., Jeremic, B., Swanson, R. and Franc, M. "Mechanics of Granular Materials at Low Effective Stresses." **Accepted** for publication in *J Aerospace Engineering* July 1998.

Yang, T. C., George, K., Johnson, A. S., Durante, M., Fedorenko, B. S. "Biodosemitry results from Space Flight *Mir*-18." *Radiation Research*, 148 (5 Suppl): S17-S23, (1997).

Attachment 11.6: Phase 1 Symposia Presentations

Presentations From August 5 - 7, 1997 Symposium

Attachment 11.6: Phase 1 Symposia Presentations Continued

Presentations From March 31-April 2, 1998 Symposium

STS-63 and STS-86 cosmonaut Vladimir Titov conducts an experiment in the Spacehab module

NASA 4 astronaut Jerry Linenger